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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : F16K 11/02

A1

(11) International Publication Number: WO 00/23734

(43) International Publication Date: 27 April 2000 (27.04.00)

(21) International Application Number: PCT/US99/23878

(22) International Filing Date: 14 October 1999 (14.10.99)

(30) Priority Data:
09/174,131 16 October 1998 (16.10.98) US

(71) Applicant: DANIEL INDUSTRIES, INC. [US/US]; 9753 Pie Lake Drive, Houston, TX 77055 (US).

(72) Inventors: XU, Yang; 5900 Ranchester #612, Houston, TX 77036 (US). LECHNER-FISH, Teresa; 22410 Cove Hollow Drive, Katy, TX 77450 (US).

(74) Agents: GRAY, Robert; Conley, Rose & Tayon, Suite 1800, 600 Travis, Houston, TX 77002 (US) et al.

(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

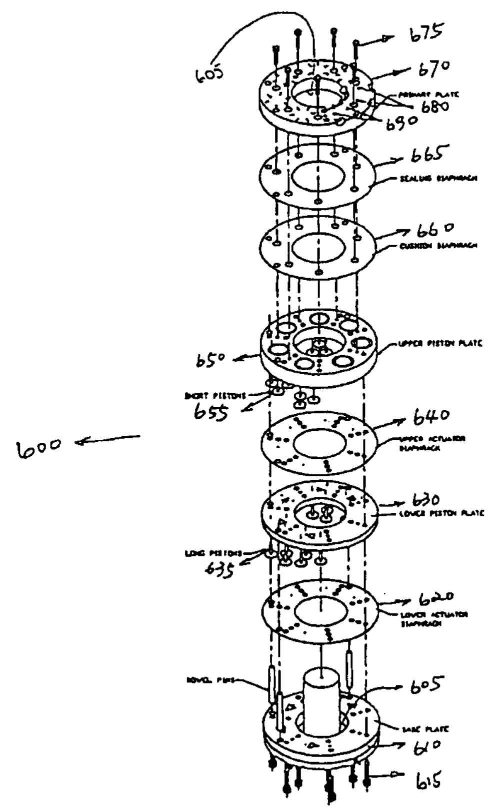
Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: IMPROVED INTEGRATED VALVE DESIGN FOR GAS CHROMATOGRAPH

(57) Abstract

A gas chromatograph (600) with multiple valves (635, 655) is disclosed. An embodiment of the multi-valve gas chromatograph includes multiple valves, multiple thermal conductivity detectors (TCD's), and a manifold. This allows separation and measurement of a gas sample in one compact integrated unit. The unit is particularly desirable because the solenoids associated with the valves are attached directly to the underneath of the manifold, thus eliminating the need for tubing between the solenoids and the valves. Other features may also be present. For example, a leak free multi-valve block may include a first temperature zone heating the valves and detectors and a second temperature zone heating the columns. The leak free feature may be achieved by placement of tightening screws through the center of each valve. Carrier gas insertion areas may be provided in the multi-valve block to improve performance. Improved separation of the temperature zones leading to further gains in performance can be achieved by use of both a thermal insulator and an air gap. Further, the temperature sensors placed in the first temperature zone can be ideally located to minimize measurement error, resulting in yet further performance gains.



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IMPROVED INTEGRATED VALVE DESIGN FOR GAS CHROMATOGRAPH

CROSS-REFERENCE TO RELATED APPLICATIONS

Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to the field of gas chromatography. In particular, this invention relates to a new gas chromatograph. Even more particularly, this invention relates to a new gas chromatograph having multiple valves and detectors.

Description of the Related Art

The field of gas chromatography is concerned with analyzing gas samples flowing through a process pipeline. A sample is provided to a gas chromatograph, which then separates the sample into portions and uses a variety of detectors to analyze the concentration of particular components in the process stream.

Before now, a number of problems have existed with gas chromatographs. For example, fast and accurate measurements are desirable for any gas chromatograph. A gas stream flowing through the process pipeline may be composed of many different classes of components and ideally, each of these components would be analyzed. However, conventional gas chromatographs cannot respond to process changes as quickly as desired. Further, liquid contaminants in the process stream can introduce further complications to any analysis.

Another problem with previous gas chromatographs is a lack of flexibility in analysis of the gas stream. It would often be desirable to analyze different characteristics of the gas stream without switching to another gas chromatograph. However, previous gas chromatographs are restricted because of their limited number of valves and by their lack of flexibility. As such, a gas chromatograph is needed that can analyze complex process streams with greater accuracy and speed.

Other problems with gas chromatographs have also existed in the valve system contained in gas chromatographs. For example, these valves are not easy to service. Maintenance may be necessary because often the flows through a gas chromatograph are dirty, and this contamination can affect the performance of key components in the gas chromatograph. Substitution of clean

components in the gas chromatograph can minimize the problem, but disassembling the gas chromatograph has in the past been a difficult and frustrating experience. Thus, a need for a new gas chromatograph exists.

As known by those of ordinary skill, the prior art also presents other problems that should be solved or minimized.

SUMMARY OF THE INVENTION

A disclosed embodiment includes a multi-valve assembly. This multi-valve assembly includes a plurality of plates and diaphragms attached together to form a plurality of valves. One of these plates is a manifold that includes a common line passage and a plurality of actuation passages, at least one of the activation passages being connected to the common line passage, there being at least as many actuation passages as there are valves. Alternately, this embodiment may be seen as a multi-valve device including at least two valves integrated into a first region that includes a first region, a gas stream property detector such as a TCD, and a first temperature sensor. A second region integrates a second heater and a second temperature sensor, with the first region's temperature sensor and gas stream property detector lying on the same radial curve with respect to a point lying in the second region.

The invention comprises a combination of features and advantages which enable it to overcome various problems of prior devices. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description of the preferred embodiments of the invention, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more detailed description of the preferred embodiment of the present invention, reference will now be made to the accompanying drawings, wherein:

Figure 1 is a simplified diagram of a gas chromatograph system.

Figure 2 is a simplified schematic of a gas chromatograph.

Figure 3A is a schematic diagram of a valve in an ON configuration.

Figure 3B is a schematic diagram of a valve in an OFF configuration.

Figure 3C is a schematic diagram of a multiple valve system for analyzing a sample.

Figure 4 is an illustrative cut-away view of a valve.

Figure 5 is an illustrative cut-away view of a solinoid.

Figure 6 is an exploded isometric view of an embodiment of a multi-valve block.

Figure 7A is a top view of an upper piston plate for the multi-valve block of Figure 6.

Figure 7B is a bottom view of an upper piston plate for the multi-valve block of Figure 6.

Figure 8A is a top view of a lower piston plate for the multi-valve block of Figure 6.

Figure 8B is a bottom view of a lower piston plate for the multi-valve block of Figure 6.

Figure 9A is a top view of a base plate for the multi-valve block of Figure 6.

Figure 9B is a bottom view of a base plate for the multi-valve block of Figure 6.

Figure 10A is a top view of a primary plate for the multi-valve block of Figure 6.

Figure 10B is a bottom view of a primary plate for the multi-valve block of Figure 6.

Figure 11 is a sealing diaphragm for the multi-valve block of Figure 6.

Figure 12 is a cushion diaphragm for the multi-valve block of Figure 6.

Figure 13A is an upper actuator diaphragm for the multi-valve block of Figure 6.

Figure 13B is a lower actuator diaphragm for the multi-valve block of Figure 6.

Figure 14 is a cut-away view of a multi-valve assembly during operation.

Figure 15 is a top view of the bottom piece of insulation for a multi-valve assembly oven.

Figure 16 is a cross-section view of an embodiment of the multi-valve assembly.

Figure 17 is an exploded isometric view of a second embodiment of a multi-valve block.

Figure 18A is a top view of a primary plate for the multi-valve block of Figure 17.

Figure 18B is a bottom view of a primary plate for the multi-valve block of Figure 17.

Figure 19A is a top view of an upper piston plate for the multi-valve block of Figure 17.

Figure 19B is a bottom view of an upper piston plate for the multi-valve block of Figure 17.

Figure 20A is a top view of a lower piston plate for the multi-valve block of Figure 17.

Figure 20B is a bottom view of a lower piston plate for the multi-valve block of Figure 17.

Figure 21A is a top view of a base plate for the multi-valve block of Figure 17.

Figure 21B is a bottom view of a base plate for the multi-valve block of Figure 17.

Figure 22 is a view of a lower sealing diaphragm of Figure 17.

Figure 23 is a view of a lower actuator diaphragm of Figure 17.

Figure 24 is a view of a upper actuator diaphragm of Figure 17.

Figure 25 is a view of a cushion diaphragm of Figure 17.

Figure 26 is a view of an upper sealing diaphragm of Figure 17.

Figure 27 is a perspective view of a multi-valve assembly including manifold and solenoids.

Figure 28A is a top view of a manifold for the multi-valve block of Figure 17.

Figure 28B is a bottom view of a manifold for the multi-valve block of Figure 17.

Figure 29 is a first cross-sectional view of the second embodiment of the multi-valve assembly

Figure 30 is a second cross-sectional view of the second embodiment of the multi-valve assembly.

Figure 31 is an illustration of a gas chromatograph system adapted for use in a refinery environment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 shows a gas chromatograph system generally built in accordance with the teachings herein. Gas flows through a process pipeline 110, a sample of which is taken by a sample probe 120 prior to being introduced to gas chromatograph (GC) 100. The gas sample may be filtered and heat traced generally along tubing 130 before flowing into gas chromatograph 100. This heating may be required for gases that may condense into a part gas, part liquid flow at cooler temperatures. After being analyzed by the gas chromatograph, the gas sample is either returned into the process pipeline 110, or vented to the atmosphere.

Referring to Figure 2, gas chromatograph 100 includes valve assembly 210 connected to multiple columns 220 and detectors 230, in this case, thermal conductivity detectors (TCD). A gas sample generally follows path 240 through valve assembly 210, columns 220 and TCDs 230. The valve assembly allows the selection of columns 220 which contain a liquid phase, or porous polymer, or other material that acts to separate the gas sample into multiple portions, each portion being sequentially released to the TCDs 230. For example, a gas sample may contain various molecular weight hydrocarbon components. Column 220 could separate the gas sample so that lower molecular weight hydrocarbon components would elute from the column first, followed by a higher molecular weight component, etc.

Referring to Figures 3A and 3B, the operation of a valve is shown. Valve 300 includes a plurality of valve ports, labeled 1-6. It will be appreciated that more or fewer number of ports may also be used. Incoming line 310 provides a gas sample to valve 300. Exhaust line 320 expels the gas sample from the valve 300. Solid lines 330 show open passages between ports, whereas dotted lines 340 indicate blocked passages between the ports.

A solenoid (not shown) places valve 300 into either an ON position, as shown in Figure 3A, or an OFF position, as shown in Figure 3B. When a valve is in the ON position, gas flows from incoming line 310, through port 1 to port 6, through line 315 and finally through port 3 to port 2 and out exhaust line 320. When the valve is in the OFF position, gas flows from incoming line 310, through port 1 to port 2 and out through exhaust line 320.

Figures 3C and 3D illustrate how a pair of valves may operate either alone or in combination with additional valves (not shown). A first valve 300 includes an array of 6 valve ports. A second valve 350 also includes an array of 6 valve ports. Associated tubing 310, 315, 320, 325 and 390, and columns 360 and 370 are also shown as well as dual TCD 380.

Incoming line 310 is attached to a sample transport line (not shown). When first valve 300 in an OFF position, gas sample flows from incoming line 310 to port 1 to port 2 of the valve 300 and out exhaust line 320. When valve 300 is in an ON position, however, gas sample flows from port 1 to port 6 and then through sample loop 315. That gas then flows from port 3 to port 2 of valve 300 and is expelled out exhaust line 320. At this time, the sample loop 315 is filled with a gas sample. This means that, if valve 300 is turned OFF at this time, a gas sample is trapped within the sample loop 315.

Turning now to valve 350, when it is in an OFF configuration, carrier gas flows from carrier gas input line 390 through port 2 of valve 350, to port 1 and then through carrier tubing 325. At this time, valve 300 is also in an OFF configuration, so that the carrier gas in tubing 325 is forced through port 5 to port 6 and through gas sample tubing 315. Consequently, this action forces the gas sample down column 360 via ports 3 and 4. The gas sample can then additionally be forced through column 370 and into the dual TCD 380 via ports 4 and 3. Many other port combinations also exist and are within the skill of one in the art. Thus, the valves may be connected in series to form "channels."

Each channel feeds into a corresponding TCD pair (a measurement TCD and a reference TCD). Use of more than one TCD pair results in a simultaneous analysis by the TCD's of the sample flowing through their corresponding attached columns. This parallel analysis results in a increased analysis speed as compared to serial analysis. Further, because technology currently limits the channels and the detector pairs to a one-to-one correspondence, the number of channels in use at any particular time is limited both by the number of valves and by the number of detectors. Of course, the greater the number of valves, the greater the number of potential channels, and the more potential for more parallel processing and a faster overall system. But even if the number of detectors limits the number of channels being used at any one time, a greater number of valves results in a greater number of channels from which to choose for each TCD. For example, a multi-valve system may have sufficient valves to operate eight channels. Even if only two detector pairs exist, such that only two channels can be in use at any one time, the detector pairs can be designed to select which channel among those eight channels it is connected to. This dramatically increases the flexibility of the presently disclosed gas chromatograph system.

Referring to Figure 4, a cross-section of a partial valve assembly is shown. Valve 400 includes a base plate 410 with activation ports 412 and 414, a lower actuator diaphragm 420, a lower piston plate 430 with associated long piston 435, upper actuator diaphragm 440, upper piston plate 450 with associated short piston 455, cushion diaphragm 460, sealing diaphragm 465, and

primary plate 470 with valve ports 472 and 474 therein. These valve ports suitably could be ports 1 and 6 as shown in Figure 3.

Referring back to Figure 4, gas sample 480 enters valve port 472. This gas sample 480 travels out valve port 474 when long piston 435 is in an elevated (closed) position and short piston 455 is not. Long piston 435 is elevated by gas pressure applied to activation port A 412. This pressure deforms lower actuator diaphragm 420 and forces long piston 435 in an upward direction in lower piston plate 430. Upper end of long piston 435 then abuts against primary plate 470. Similarly, short piston 455 is actuated by gas pressure from activation port B 414, and forces gas sample 480 to path 485.

Whether a valve is in an ON or OFF position depends upon a solenoid that applied gas pressure alternately to either activation port A or activation port B. Figure 5 generally illustrates the operation of a solenoid. Solenoid 500 includes a common line port 510, exit port 520 corresponding to activation port A, exit port 530 corresponding to activation port B, release port 525 for exit port A or exit port B, and control leads 540. Tubing 550 connects to each of common line port 510, and exit ports 520 and 530. Exit ports A and B connect to activation ports A and B in Figure 4, respectively. Common line port 510 connects to a gas under pressure. Gas pressure applied to either of activation port A or activation port B controls whether the corresponding valve is in an ON or OFF position. Electrical control signals from leads 540 control whether common line 510 is connected to exit port A or exit port B, and thus whether gas pressure is applied to activation port A or activation port B. Some variation to the particulars of this design is possible while still staying within the teachings of the invention.

Figure 6 shows an exploded view of an embodiment of the multi-valve block 600 including an open area 605, base plate 610 with associated dowel pins to align components, a lower activator diaphragm 620, a lower piston plate 630 with associated long pistons 635, an upper activator diaphragm 640, an upper piston plate 650 with associated short pistons 655, a cushion diaphragm 660, a sealing diaphragm 665, and a primary plate 670. Each piston includes a lower base portion with a pole extending therefrom. Hole sets 680 and 690 are suitable for two pairs of TCD's. First set of screws 615 for insertion through base plate 610, lower piston plate, and upper piston plate are shown as well as a second set of screws 675 for insertion through primary plate 670, upper piston plate 650, and lower piston plate 630. In addition, because there are five valves, five solenoids (not shown) are also present, each controlling a different valve.

As can be seen, the multi-valve device 600 includes 5 valves, with each valve having six ports. By integrating multiple valves into a single multi-valve block, a compact device is achieved that can separate a gas sample into a large number of columns as discussed above. This facilitates

faster and more precise analysis of the gases contained in the gas sample. Manufacturing costs can also be reduced. The teachings herein can be used to integrate more or fewer than 5 valves into a single unit, and more or fewer valve ports per valve. For example, if a greater number of valves is desired, up to 7 valves can easily be located in the embodiment shown in Figure 6.

One manner in which the embodiment of Figure 6 makes faster and more precise analysis of the gas sample is reduction of what is known as "dead volume." Increased dead volume results when the components of a gas chromatograph are widely spaced and undue mixing of the fluid occurs. This mixing of the gas or fluid sample results in a "band broadening." Band broadening is undesirable because the area of a band of an analysis corresponds to concentration and these bands should not overlap. Consequently, a series of broad bands results in a much slower analysis than is possible with a series of short, compact bands. Therefore, an integrated, compact design is particularly desirable from a performance perspective. Further, the illustrated geometry provides sufficient area for a first and second set of TCD's. While these TCD's may be located outside the multi-valve block if desired (e.g. to integrate a greater number of valves into the multi-valve block), the inclusion of the TCD's in the multi-valve block helps further miniaturize the device and make it more compact.

Figures 7A and 7B show top and bottom views respectively of the upper piston plate of Figure 6. Referring to the top view of Figure 7A, locations 701-705 for 5 valves are shown. Screw holes, generally at 720, are also shown for accepting screws to tighten together the primary plate with other plates. Holes 750 are for screws from the bottom to tighten the plates together, while holes 760 are fore dowel pins to position the valves. Turning to the bottom view of the upper piston plate shown in Figure 7B, locations 701-707 are similarly shown. Each valve includes sufficient room 730, 735 for 3 piston bases and 3 piston poles. Raised edges 740 around the perimeter of each valve location are also shown. The raised surfaces defined by the raised edges exist on both sides of the upper and lower piston plates. A raised edge of 0.032 inches could be used, for example. These raised edges 740 reduce the surface area upon which the screws 615 and 675 provide force and thereby reduce the chance of leakage.

Referring back to Figure 6, it can be seen that two sets of screws are shown corresponding to holes 720 and 750. These two sets of screws that protrude through holes 720 and 750 simplify maintenance of the invention. A bottom set of screws 615 extends through the base plate 610, lower piston plate 630, and upper piston plate 650. Screws 615 attach these plates together. A top set of screws 675 extends through the primary plate and the upper piston plate to hold those plates together. This dual screw set approach simplifies maintenance because the loosening and removal of screws 675 allows access and replacement of the sealing diaphragm 665 and cushion diaphragm

660 without disassembly of a greater number of plates than necessary. It is the sealing diaphragm that becomes most contaminated by the dirty gas that flows through the multi-valve. A relatively low torque of about 10 ft/lbs. has been found acceptable for these screw sets while making the removal of these screws as easy as possible. The multi-valve configuration also simplifies maintenance because, by virtue of multiple valves in an integrated unit, replacement of only one diaphragm is necessary rather than the multiple diaphragms that would otherwise be necessary for multiple valves.

Figures 8A and 8B show the lower piston plate of Figure 6. Figures 8A and 8B are the upper and lower views respectively of the lower piston plate. Referring to Figure 8A, once again, locations 801-805 are provided for the five valves, in addition to an area for two sets of TCDs. Holes 820 and holes 825 accept tightening screws. Also shown are five triangular grooves 830 and accompanying holes 840 within each groove. Gas from the solenoids travels through the actuation holes 840 to the grooves 830. These grooves 830 provide a path for the actuation gas that elevates the short pistons. Because the valves of the illustrated embodiment have six ports, and thus three short pistons per valve, a triangular shape is convenient (but not necessary) to actuate all three short pistons simultaneously. Turning now to the bottom view of Figure 8B, locations 801-807 are shown. Also generally shown at 840 are holes connected to an actuator port through which gas exerts pressure. These holes 840 correspond to the grooves 830 of Figure 8A. As can be seen, space 830 is provided for the base of long pistons 635.

Figures 9A and 9B show the top and bottom views respectively of the base plate. Referring to Figure 9A, similar to Figure 8A, a plurality of grooves 930 are shown, with each groove encompassing a hole 940 for actuator gas. In addition, actuator holes 945 traveling up to the lower piston plate are additionally shown. Figure 9B illustrates the bottom view of the base plate. Illustrated are slot 960 and holes 970, 980, and 990. Slot 960 is present because it simplifies the removal of diaphragms upon disassembly. In particular, after a valve has been assembled, the diaphragms tend to stick to a contact surface, and the slots provide an area where the diaphragms can be easily grabbed onto. Hole 970 is a port A and B common line that connects to port A and B on solenoids via tubing. Holes 980 and 990 are screw holes. Figure 9B also shows cross-drill lines 962 and 964 representing drilled areas for insertion of carrier and sample gas tubing. Holes at the entrance to each insertion area are also shown. The carrier and sample gas are quickly and reliably preheated in the insertion areas defined by cross-drill lines 962 and 964 from the warmth in the multi-valve block.

Figures 10A and 10B show the upper and lower view of a primary plate of Figure 6. Referring now to Figure 10A shown are TCD holes 1050-1053 and associated tubing holes 1060-

1063. Also shown is a hole 1070 suitable for a RTD heat sensor. Figure 10B shows a bottom view of the primary plate. Included are holes 1010 to accept screws and 1020 to accept dowel pins.

Figures 11-13 illustrate the diaphragms of Figure 6. Figure 11 shows the sealing diaphragm of Figure 6. The sealing diaphragm is preferably made from 2mil thick Kapton™ made by DuPont with a 0.5mil teflon coating on each side. Figure 12 shows the cushion diaphragm of Figure 6. The cushion diaphragm is preferably about 0.002" thick and is made from Nomax paper by DuPont. Figures 13A and 13B illustrate upper and lower actuator diaphragms. Both actuator diaphragms are preferably made from 3 mm thick Kapton™ made by DuPont.

Figure 14 illustrates a multi-valve block 1400 including a spool 1410 with areas for a first RTD (Resistance Thermal Detector) 1420 and two TCD pairs 1425, an exterior surface 1430 to the multi-valve block 1400, a band heater 1440 outside of the exterior surface 1430, carrier gas preheat tubing 1450 located between the exterior surface 1430 and the band heater 1450, and a base plate 610 as part of the multi-valve block. Spool 1410 contains one or more cartridge heaters 1460 and a second RTD 1465. Referring back to Figure 6, a hole or open area 605 is present in the middle of the multi-valve block. The open area 605 accommodates spool 1410 that protrudes from the base plate 610. Columns 1470 wraps around the spool 1410. Also shown are solinoids 1480 connected via tubing 1485 to the base plate at its lower end 1490. Band heater 1440 is an AC band heater of approximately 200 Watts power.

During operation, a gas sample flows through tubing or conduits 315 (not shown in Figure 14) in the multi-valve block prior to flowing through the piping of the columns 1470. In contrast, the carrier gas flows through the carrier gas preheat tubing 1450 prior to flowing through columns 1470. The carrier gas preheat tubing may be located at different positions to heat the carrier gas to a predetermined temperature. The carrier gas preheat tubing may be just inside the band heater as shown in Figure 14, or it may preferably occupy insertion areas in the multi-valve block, as explained in reference to Figure 9. Thus, prior to being warmed by the spool, both the carrier gas and the gas sample are heated to approximately the temperature of the multi-valve block.

Thus, this arrangement provides for two heating zones. The area proximate to the spool 1410 defines a second heating zone. A first heating zone is defined by the temperature of the remainder of the multi-valve block. The first RTD located in the multi-valve block at 1420 measures the temperature of the first heating zone. The second RTD located at 1465 within the spool 1410 measures the temperature of the second heating zone. Two separate heating zones are important because the gas flowing through the columns 1470 should ideally be about 3 - 5° C higher than the temperature at each TCD (the temperature of the first heating zone). In addition, the TCD's in the first heating zone should be kept to within about 0.1° C of a predetermined temperature for

accurate analysis. The temperature variation in the second heating zone should also be maintained within about a 0.1° C tolerance. More heating zones may be added when desired to allow the analysis of the complex samples.

In order to stabilize the temperatures in heating zones, an "oven" is created from a thermal insulation material. This oven is essentially a cylindrical sleeve that surrounds the rest of the multi-valve device and keeps its temperature stable, except for the solinoids, which must be kept away from the heat inside the oven. Referring to Figure 15, an illustrative bottom 1500 of this insulation cylinder or sleeve is shown. As can be seen, it contains a number of holes 1510, through which extend the tubing for the solinoids and the legs of the base stand.

Figure 16 illustrates the insulation 1610 for the "oven" including the bottom 1500 of the insulation cylinder. As part of them multi-valve block 1400, base plate 610 is adjacent to the bottom of the insulation cylinder 1500. Legs 1600 to create stand-off are made from Teflon™ 1605. Also shown is tubing 1485 that extends through the bottom piece 1500 to the lower surface 1490 of the multi-valve block 1400.

A second embodiment of the invention was developed subsequent to the above embodiment and is shown in Figures 17-30. This embodiment of the invention is believed to be improved in a number of respects to the first embodiment. Figure 17 shows an exploded view of the second embodiment for a multi-valve block 1700 in an inverted configuration. Such an inverted configuration is preferred to simplify assembly. Figure 17 includes an Ultem™ manifold 1780 with associated Ultem™ plug 1782. Also shown are lower sealing diaphragm 1765, base plate 1710 with carrier gas preheat coil insertion areas, lower actuator diaphragm 1720, lower piston plate 1730 with associated long pistons 1735, upper actuator diaphragms 1740, upper piston plate 1750 with associated short pistons 1755, cushion diaphragm 1760, sealing diaphragm 1775, and primary plate 1770 with associated guide pins 1172. Also shown are an open area 1705 in the center of the multi-valve block, torque screws 1790, and Belleville washers. Insulation plugs 1704 are inserted after torque screws 1790 have been tightened through the manifold 1780. Screws 1795 are also shown.

Figures 18A and 18B show the upper and lower view of a primary plate of Figure 17. Referring now to Figure 18A, five valves 1801-1805 with 6 ports 1810 each are shown, as well as TCD holes 1850-1853 and associated tubing holes 1860-1863. A hole 1870 is suitable for an RTD heat sensor, and is set by set screws in hole 1875. Holes 1820 are for tightening screws. Hole 1835 is for mounting support of TCD terminal block. In contrast to the hole for the RTD heat sensor of Figure 10, RTD heat sensor hole 1870 is located in the same radial circle as the TCD holes 1850-1853. As can be appreciated, because the temperature at the TCD is extremely important to the accurate measurement of the gas sample, a temperature sensor (RTD) should be placed as close as

possible to the TCD. RTD heat sensor hole 1870 accomplishes this. But further, because of the mass of a multi-valve block, temperature gradients across the block can be significant. The placement of RTD heat sensor hole 1870 in the same radial circle as the TCD holes minimizes error from any temperature gradient across the multi-valve block. Figure 18B shows a bottom view of the primary plate. Included are holes 1810 corresponding to the valve ports of Figure 18A, and holes 1820 for tightening screws. Slot 1870 to simplify maintenance and dowel pin holes 1880 are also shown.

Figures 19A and 19B show top and bottom views respectively of the upper piston plate of Figure 17. Referring to the top view of Figure 19A, locations 1901-1905 for 5 valves are shown. Screw holes, generally at 1920, are also shown for accepting screws to tighten together the multi-valve block. Holes 1940 are for screws from bottom to tighten together the valve block. As explained with respect to the first embodiment, the dual screw sets of this embodiment considerably simplify maintenance of this embodiment as compared to prior art valves. Turning to the bottom view of the upper piston plate as shown in Figure 19B, slots 1960 simplify maintenance as generally explained above with respect to the first embodiment. Locations 1901-1905 are for the five valves. Each valve location 1901-1905 includes sufficient room 1930, 1935 for 3 piston bases and 3 piston poles.

Unlike the upper piston plate of the first embodiment as shown in Figure 7, the second embodiment does not include raised edges to reduce the chance of leakage. The raised edges 740 of the first embodiment were not desirable because significant manufacturing costs were required to obtain such an edge. Instead, some other way of reducing the chance of leakage was sought. The second embodiment reduces the chance of leakage without raised edges by placement of the tightening holes 1920 within the confines of each valve. In particular, the tightening holes 1920 are located at the center of each valve. This results in a leak-free fit for the multi-valve block without the added expense of raised edges.

Figures 20A and 20B show the lower piston plate of Figure 17. Figures 20A and 20B are the upper and lower views respectively of the lower piston plate. Referring to Figure 20A, once again, locations 2001-2005 are provided for the five valves. Holes 2080 are screw holes, while holes 2085 are dowel pin holes. Also shown are five triangular grooves 2030 and accompanying holes 2040, as well as holes 2020. to accept tightening screws in the center of each groove 2030. Gas from the actuation ports flows through the holes 2040. The grooves 2030 provide a path for the actuation gas, resulting in a simultaneous elevation and actuation of the short pistons. Because the valves of the illustrated embodiment have six ports, and thus three short pistons per valve, a triangular shape is convenient (but not necessary) to actuate all three short pistons simultaneously.

The triangular grooves of the second embodiment are somewhat larger than those of the first as shown in Figure 8, to accommodate the tightening holes 2020 in their centers. Turning now to the bottom view of Figure 20B, locations for the valves are shown, in addition to slots 2060. As can be seen, Figure 20B also includes space 2030 for the base of long pistons 635, tightening screw holes 2020, and other features explained in reference to other Figures herein.

Figures 21A and 21B show the top and bottom views respectively of the base plate 1710. Referring to Figure 21A, holes 2160 and a plurality of triangular grooves 2130 are shown, with each groove encompassing a hole 2140 for actuator gas. Additional holes 2145 forming a path for actuator gas to elevate the short pistons is also shown. Line 2150 indicates an elevation edge down to an area 2152. Area 2152 is an insulating air gap whose function is explained below. Other features are also shown that have been explained in reference to the other Figures. Figure 21B illustrates the bottom view of the base plate 1710. Shown are actuator gas paths 2155, as well as screw holes 2170 and 2180. Pin holes 2185, and shape silhouettes 2190 are also shown. Shape silhouettes 2190 indicate the locations for the preheat coil insertion areas. The carrier gas in these preheat coils is thus warmed by the multi-valve block. Holes 2170 and 2180 are screw holes. Holes 2185 are dowel pin holes.

Figures 22-26 illustrate the diaphragms of the second embodiment. In particular, Figure 22 illustrates a lower sealing diaphragm of the second embodiment. This diaphragm is preferably a 5mil Teflon sheet and ensures a leak-free fit between the manifold and the base plate. There is no corresponding diaphragm on the first embodiment. Figure 23 illustrates a lower actuator diaphragm of the second embodiment. Figure 24 illustrates an upper actuator diaphragm of the second embodiment. Figure 25 illustrates a cushion diaphragm of the second embodiment. Figure 26 illustrates an upper sealing diaphragm of the second embodiment. Each diaphragm includes holes whose purpose is explained with respect to other Figures. These diaphragms are preferably made from the same material as the corresponding diaphragms of the first embodiment.

Referring now to Figure 27, the second embodiment includes an insulation manifold 1780 instead of the base insulation piece of the first embodiment. Also shown are solenoids 2980, the multi-valve block, a column cup 2920, column support 2727, and a column cover 2745. To simplify viewing of the multi-valve assembly, not shown in Figure 27 is the remainder of the oven insulation that surrounds the multi-valve assembly. As can be seen, one advantage of manifold 1780 is that the solenoids attach directly to its lower surface and thus tubing between the solenoids and the multi-valve block is eliminated. This elimination of tubing between the solenoids and the multi-valve block results not only in a substantial savings, but also a quicker response time during analysis.

Figures 28A and 28B are top and bottom views of the manifold 1780. Figure 28A shows a universal common line hole 2800 and a common line gas passage 2810 from the common line hole 2800 to a center groove 2820. Also extending from center groove 2820 are a plurality of solenoid actuation passages 2831-2835, one for each solenoid (not shown).

Figure 28B illustrates many of the same elements as Figure 28A. Referring now to Figures 28A and 28B, during operation, a single tube carrying actuator gas connects to universal common line hole 2800. From there, actuator gas travels through common line gas passage 2810 to center groove 2820. Actuator gas then travels to each individual solenoid via the solenoid passages 2831-2835. At that time, the actuator gas enters each solenoid (not shown), the solenoids being attached firmly to the bottom of the manifold by use of screw holes 2860. The actuator gas travels through the solenoids and exits through the actuator gas holes 2850 or 2855 to place the valves in either an ON or OFF configuration.

Figure 29 shows the multi-valve assembly of the second embodiment during operation. To simplify viewing, the oven for the multi-valve assembly is not shown. Multi-valve block 2900 includes areas for a first RTD in the same radial plane as the hole for the two TCD pairs 2925, an exterior surface 2930 to the multi-valve block 2900, a band heater 2940 outside of the exterior surface 2930, carrier gas preheat coil 2950, and a base plate 1710. Spool 2910 contains a cartridge heater 2960 and a second RTD 2965. Unlike the first embodiment, a thermal insulation cup 2920 and an air gap 2925 separate the spool and the base plate. The columns 2970 wrap around the spool 2910. An ULTEM manifold 2990 is attached. Also shown are solenoids 2980 connected to the manifold 2990 at its lower end.

Referring back to Figure 17, a hole or open area 1705 is present in the middle of the multi-valve block. This open area accommodates spool 2910. Thermal insulation cup 2920 and air gap 2925 insulate the spool from the base plate. Thermal insulation cup 2920 is preferably made from nylon. The thermal insulation cup and air gap are significant features of the second embodiment because, as explained, the multi-valve assembly defines two heating zones, each of which should be carefully monitored and maintained. The design of the second embodiment separates these two heating zones by the thermal insulation cup and air gap and therefore helps to achieve temperature stability in each.

Carrier gas preheat tubing 2950 is coiled in holes formed in the body of multi-valve block 2900, and the carrier gas is thus warmed by the heat in the multi-valve block. Band heater 2940 is a DC band heater of approximately 30 Watts power. The substitution of this DC band heater in lieu of the AC band heater of the first embodiment improves the performance of the multi-valve

assembly by smoothing out the temperature fluctuations and eliminating electrical noise, and is another improvement over the first embodiment.

Figure 30 illustrates a multi-valve assembly including oven insulation. The multi-valve assembly includes a multi-valve block 3000 including a base plate 3010 and manifold 3040. Also shown are torque screws 3020 with associated insulation plugs 1704, standoffs 3060, oven insulation 3050 and solenoid 3080. As can be seen, solenoid 3080 is immediately adjacent the manifold 3040. Actuator gas 3030 flows through the manifold to the solenoid, and then back through the manifold to actuate the appropriate pistons. The oven insulation 3050 of the second embodiment is generally of the same material as the first embodiment, but it is covered with stainless steel around its exterior 3055 to provide reinforcement.

In addition eliminating the need for tubing from the solenoids to the multi-valve assembly, manifold 3040 offers a number of advantages over a bottom piece of insulation. The manifold has good insulation properties. It has been found that ULTEM has the requisite mechanical strength and insulation characteristics, and works very well for such an application, although it is likely not the only appropriate material. ULTEM™ is made by Commercial Plastics, Inc. As an additional feature, instead of being far removed from the multi-valve block, the manifold design allows placement of the solenoids adjacent to the manifold and thus proximate to the base plate. This makes the whole assembly more compact and also increases the response time.

The insulation material has also been modified by placing steel around its exterior. This results in an increased resistance to warping as well as increased durability and ruggedness.

The teachings herein can be adapted to a variety of environments. Figure 31 shows a multi-valve assembly 3100 suitable for use in a refinery environment. A multi-valve block 3110 including a column area 3115, TCD 3120, auxiliary column oven 3130, and surrounding environment, generally at 3140. With this arrangement, the multi-valve block 3110 has room for a greater number of valves because the TCD 3120 is located outside the multi-valve block. This is a desirable feature when analyzing complex refinery samples. Also shown is an auxiliary oven that may be either warmer or cooler than the multi-valve block. This auxiliary oven provides for a greater number of heating zones for chromatography columns with a corresponding increase in analysis flexibility. Further, because of the refinery environment in which this arrangement can be used, by moving the gas sample analyzer (in this case a TCD outside of the multi-valve block), a more stable temperature is achievable around the TCD 3120. The heater in this embodiment may preferably be an air-bath oven. This further increases the accuracy of the system.

Thus, while preferred embodiments of this invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit or

teaching of this invention. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the system and apparatus are possible and are within the scope of the invention. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims.

CLAIMS

WHAT IS CLAIMED IS:

1. A multi-valve assembly comprising:

a plurality of plates and diaphragms attached to form a plurality of valves, each valve capable of being individually activated by actuation pressure, wherein

one of said plurality of plates is a manifold, and said manifold includes a first common line passage suitable to carry an actuation fluid applying said actuation pressure;

a plurality of actuation passages, there being at least as many of said actuation passages as there are of said valves;

said first common line connecting to at least one of said plurality of actuation passages.

2. the multi-valve assembly of claim 1, further comprising:

a plurality of solenoids attached to said manifold.

3. The multi-valve assembly of claim 2, wherein said plurality of solenoids are attached directly to a bottom of said manifold, said bottom being defined with respect to the remainder of said plurality of plates.

4. The multi-valve assembly of claim 1, wherein said common line passage connects to each of said plurality of actuation passages by a groove in said manifold.

5. The multi-valve assembly of claim 1, wherein said manifold is made from an insulative material.

6. The multi-valve assembly of claim 5, wherein said manifold forms a portion of an insulative oven encapsulating the remainder of said plates.

7. The multi-valve assembly of claim 5, further comprising at least one of said valves attached to a length of tubing holding a fluid,

said tubing being inserted in insertion holes in at least one of said plates, resulting in an efficient heat transfer between said plate and said tubing.

8. The multi-valve assembly of claim 5, further comprising:

a set of tightening screws wherein each of said valves defines a valve region and at least one of said set of tightening screws is inserted through each of said valve regions.

9. A multi-valve device, comprising:

at least two valves integrated into a first region, said first region also including a first heater, a gas stream property detector, and a first heat sensor;

a second heater and a second temperature sensor integrated into a second region;

said first temperature sensor and said gas stream property detector lying on the same radian curve with respect to a point lying in said second region.

10. the multi-valve device of claim 9 further comprising:

a thermal insulation;

said first region and said second region being separated by said thermal insulation.

11. The multi-valve device of claim 10, further comprising:

an air gap, said air gap also separating said first region and said second region.

12. The multi-valve device of claim 9, wherein said first heater lies along the outer periphery of said first region and said second region lies inside said first region.

13. The multi-valve device of claim 12, wherein said heater is a DC band heater.

14. The multi-valve device of claim 9, further comprising:

a set of screws, wherein one of said set of screws is located through a center for each of said valves.

15. The multi-valve device of claim 9, further comprising:

a manifold with directly attached solenoids, said manifold providing a passage for actuation fluid used by said solenoids, whereby said actuation fluid passes from said manifold to said solenoid and then through said manifold.

16. The multi-valve device of claim 9, further comprising:

insertion areas in said multi-valve device, said insertion areas being suitable to hold coiled tubing.

17. The multi-valve device of claim 9, including at least five valves.

18. A multi-valve block, comprising:

means for directing a flow of gas among a plurality of paths;

means for detecting properties for said flow of gas.

19. The multi-valve block of claim 18, further comprising:

means for heating at least a portion of said multi-valve block to a predetermined temperature;

means for detecting a temperature proximate to said means for heating.

20. The multi-valve block of claim 18, further comprising:

means for ensuring that said paths are leak free, said means for ensuring also being means to partially disassemble said multi-valve block.

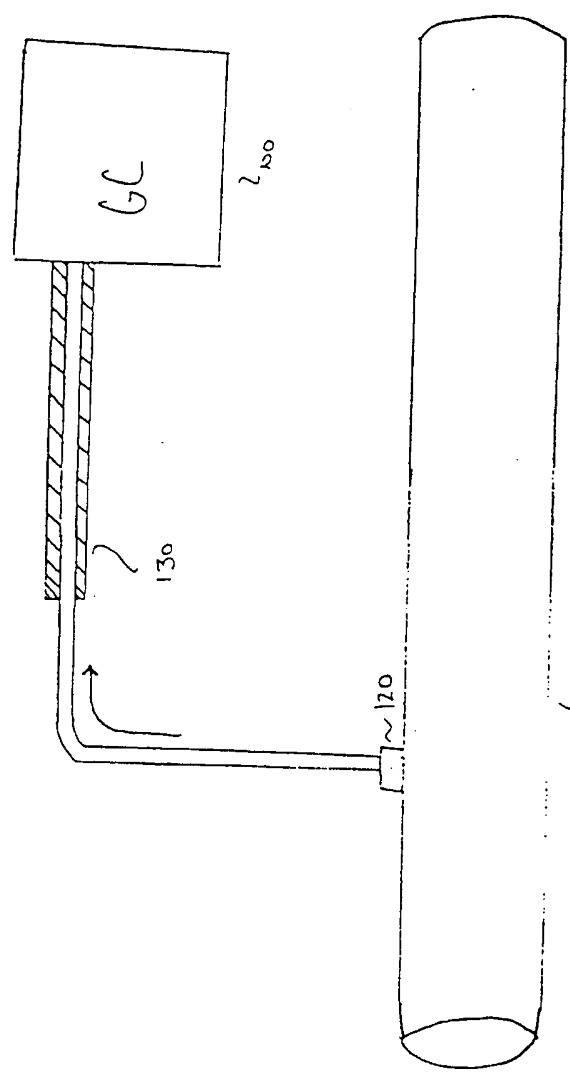


Fig. 1

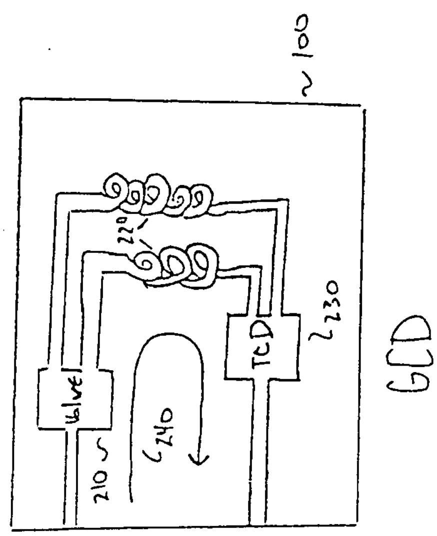
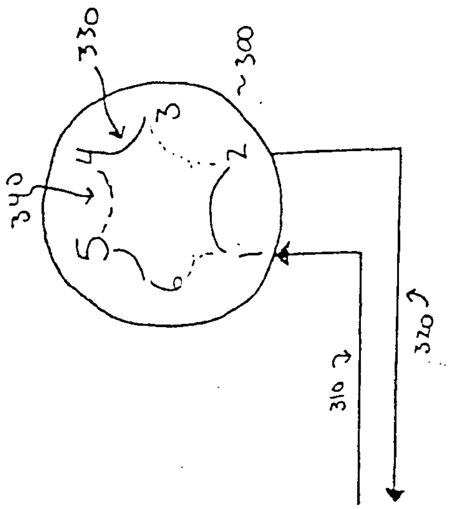
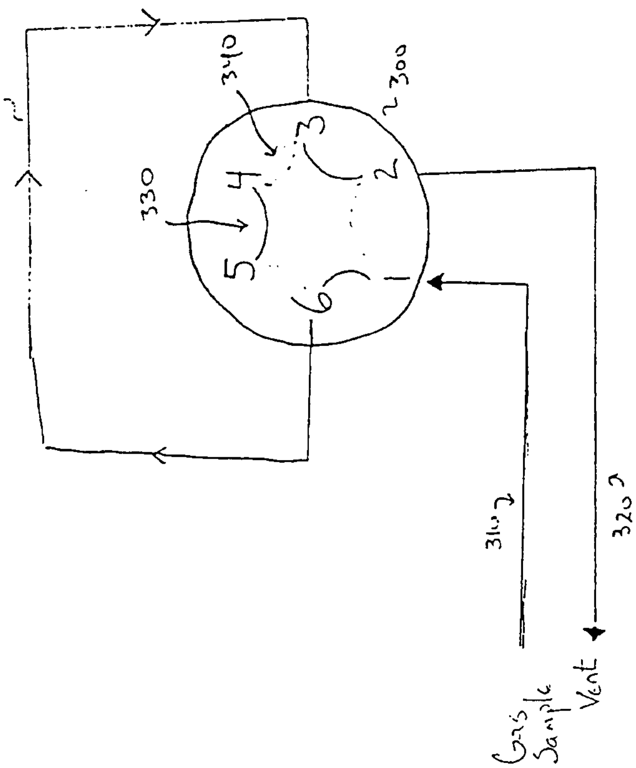


Fig. 2



OFF

Fig 3B



ON

Fig. 3A

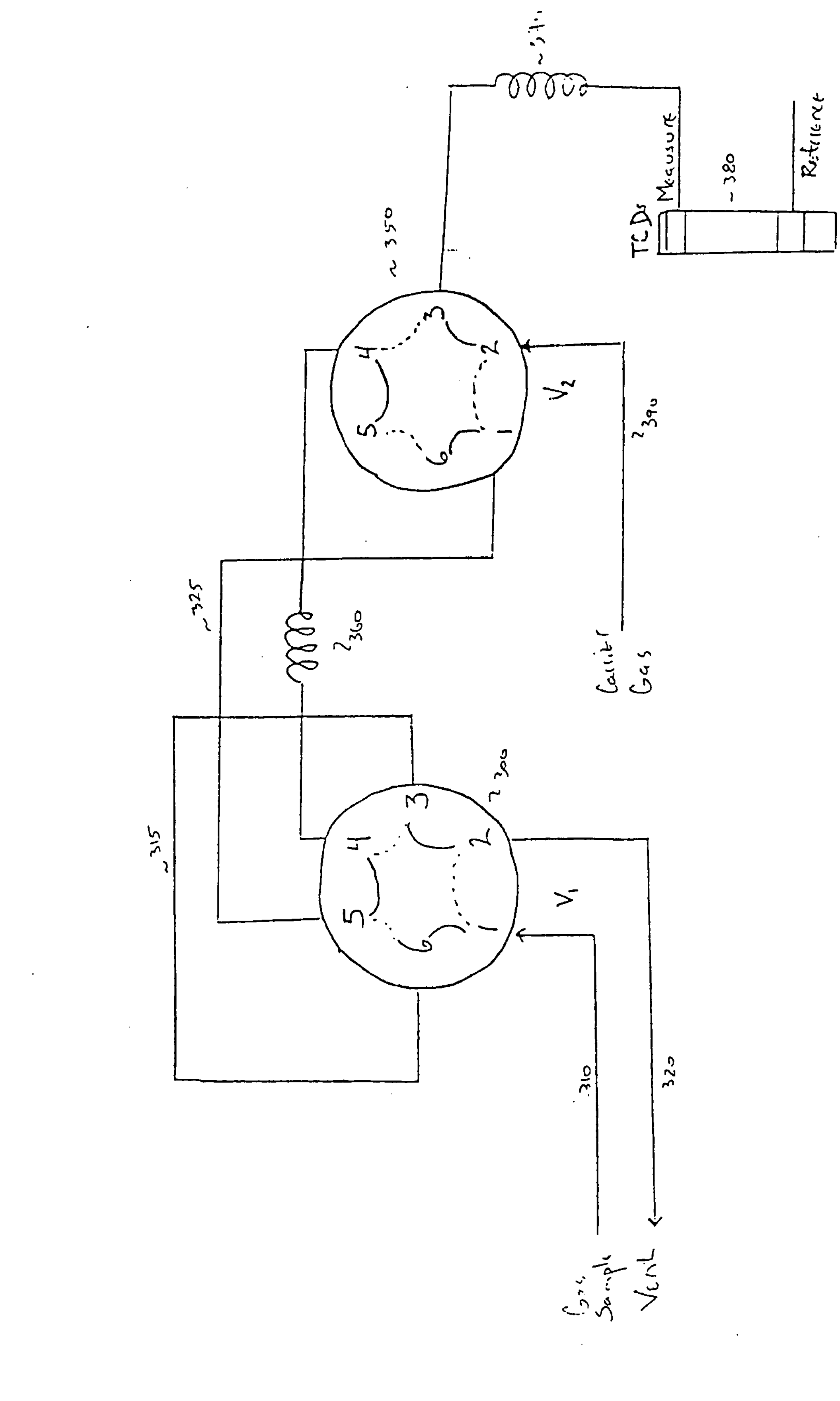

Measure
Reference
TCDs
380
350
V_2
390
Carrier Gas
325
360
315
300
V_1
310
320
Sample
Vent

Fig. 3C

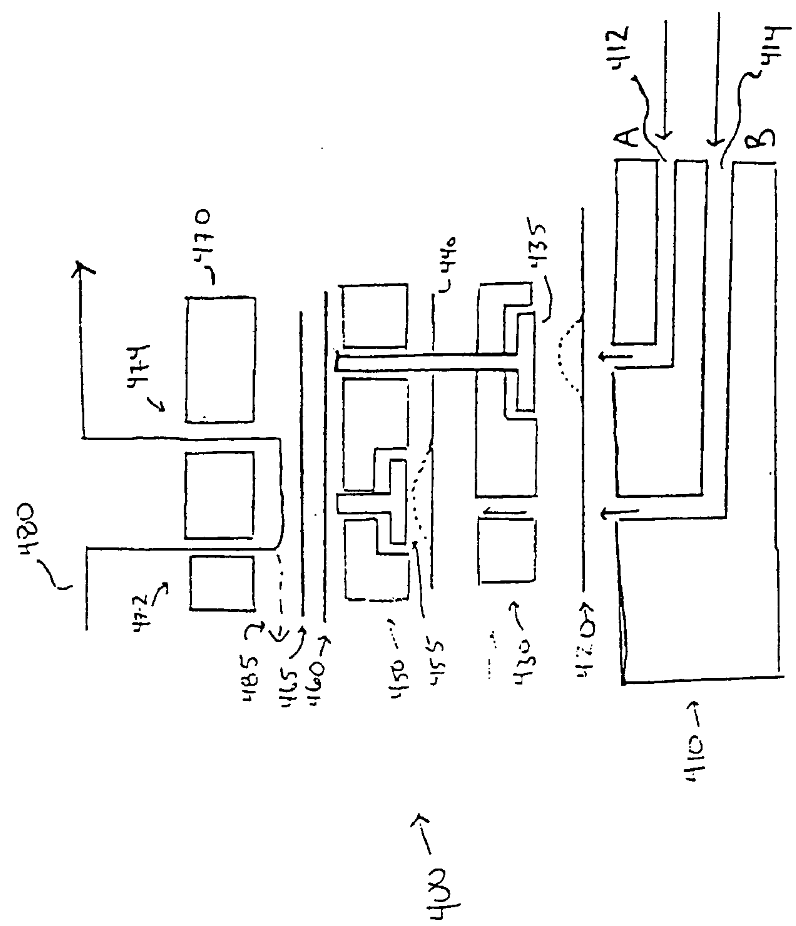

480
474
470
472
485
465
460
450
455
440
435
430
420
410
412
414
A
B
400

Fig. 4

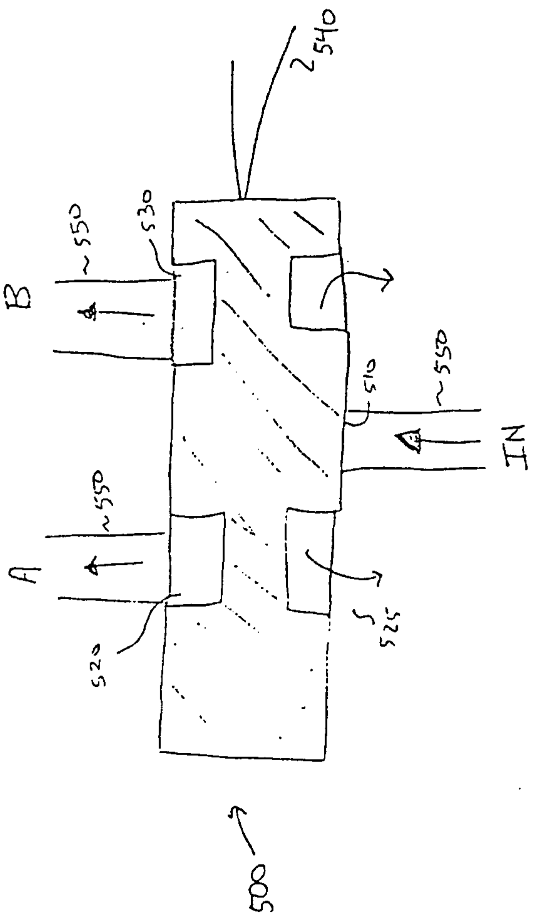


Fig. 5

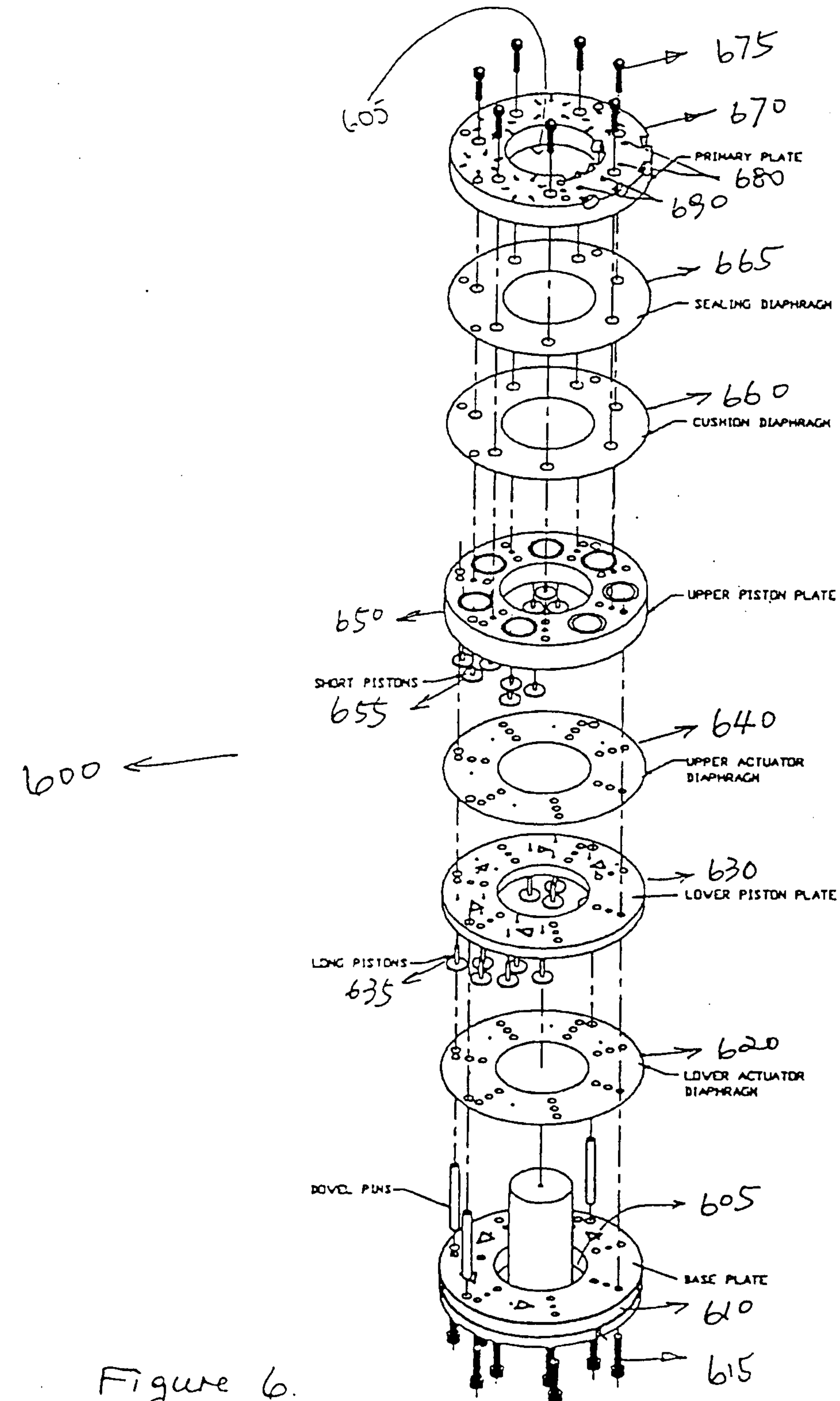

675
605
670
PRIMARY PLATE
680
690
665
SEALING DIAPHRAGM
660
CUSHION DIAPHRAGM
UPPER PISTON PLATE
650
SHORT PISTONS
655
640
UPPER ACTUATOR DIAPHRAGM
600
630
LOWER PISTON PLATE
LONG PISTONS
635
620
LOWER ACTUATOR DIAPHRAGM
DOWEL PINS
605
BASE PLATE
610
615

Figure 6.

Piston Plate

Top

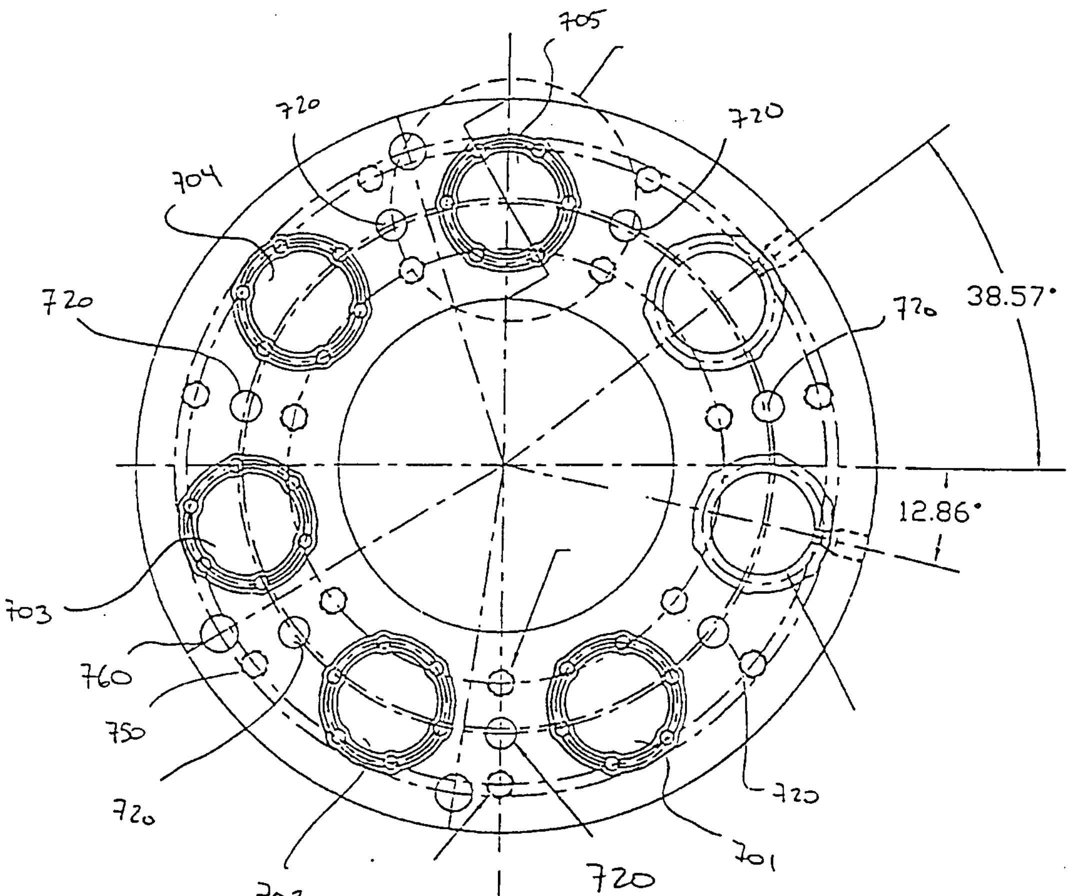


Fig. 7A

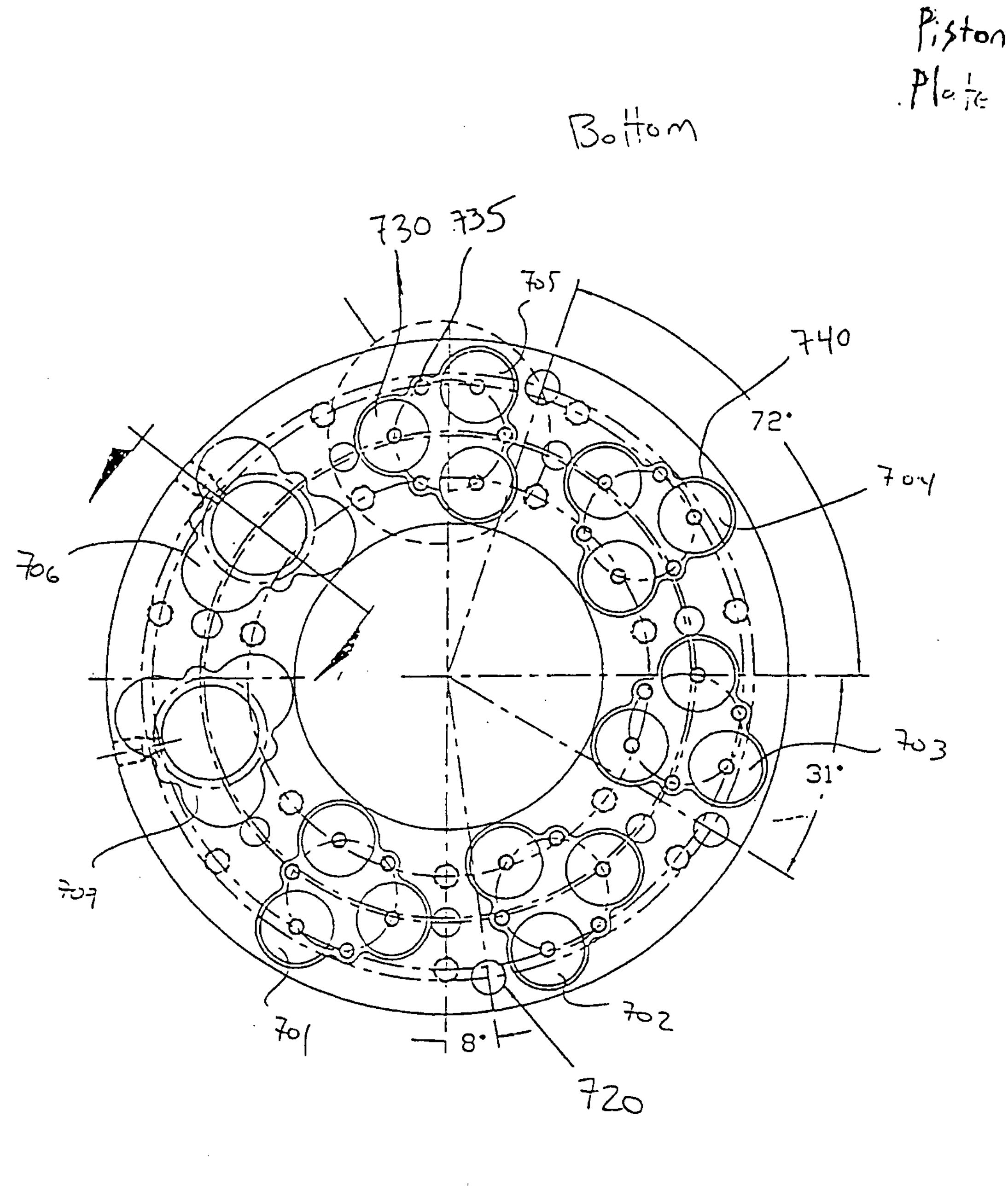

Piston
Plate
Bottom
730
735
705
740
72°
704
706
703
31°
707
701
8°
702
720

Fig. 73

Lower Piston Plate

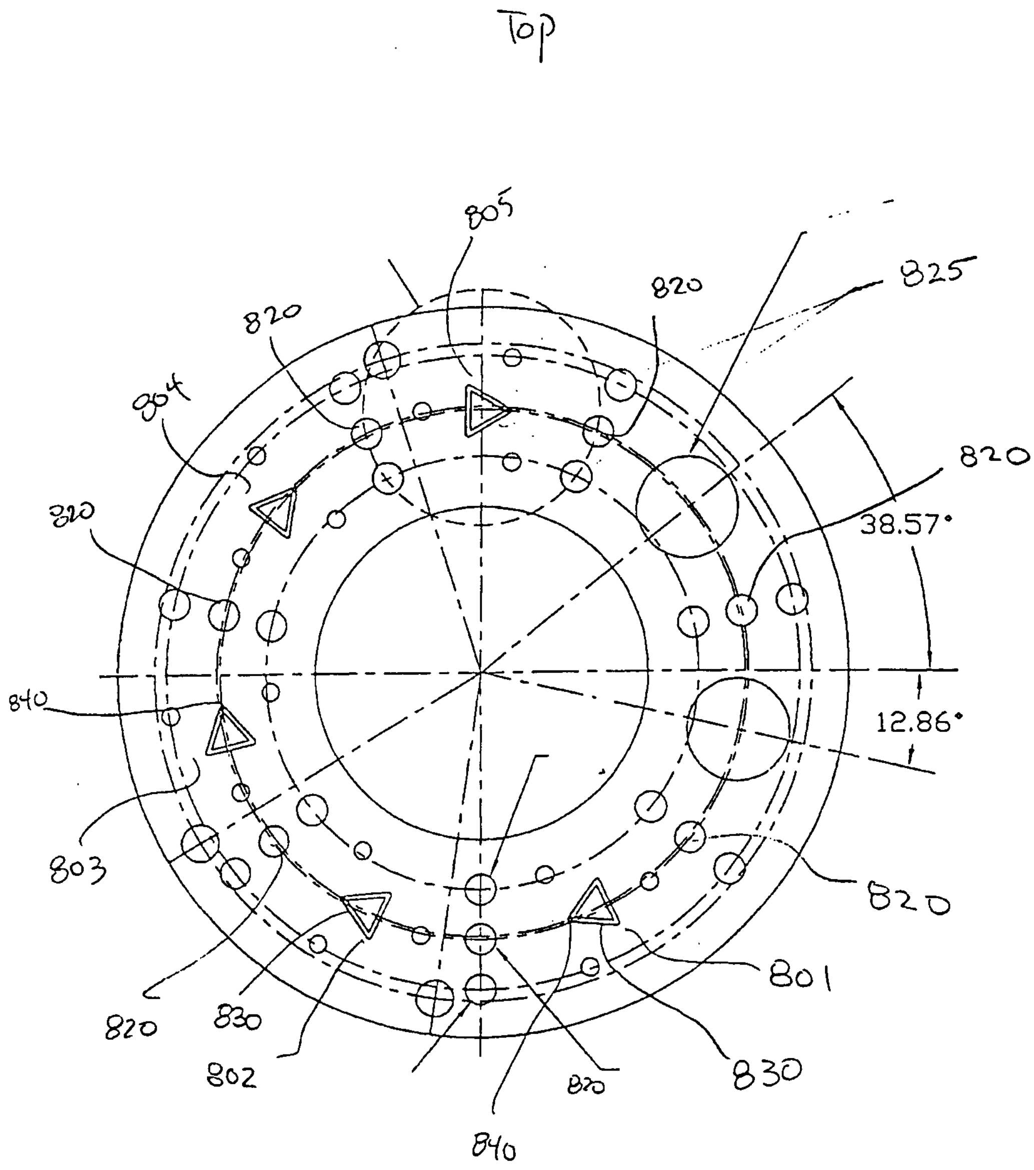


Fig. 8A.

Lower
Piston
Plate

Bottom

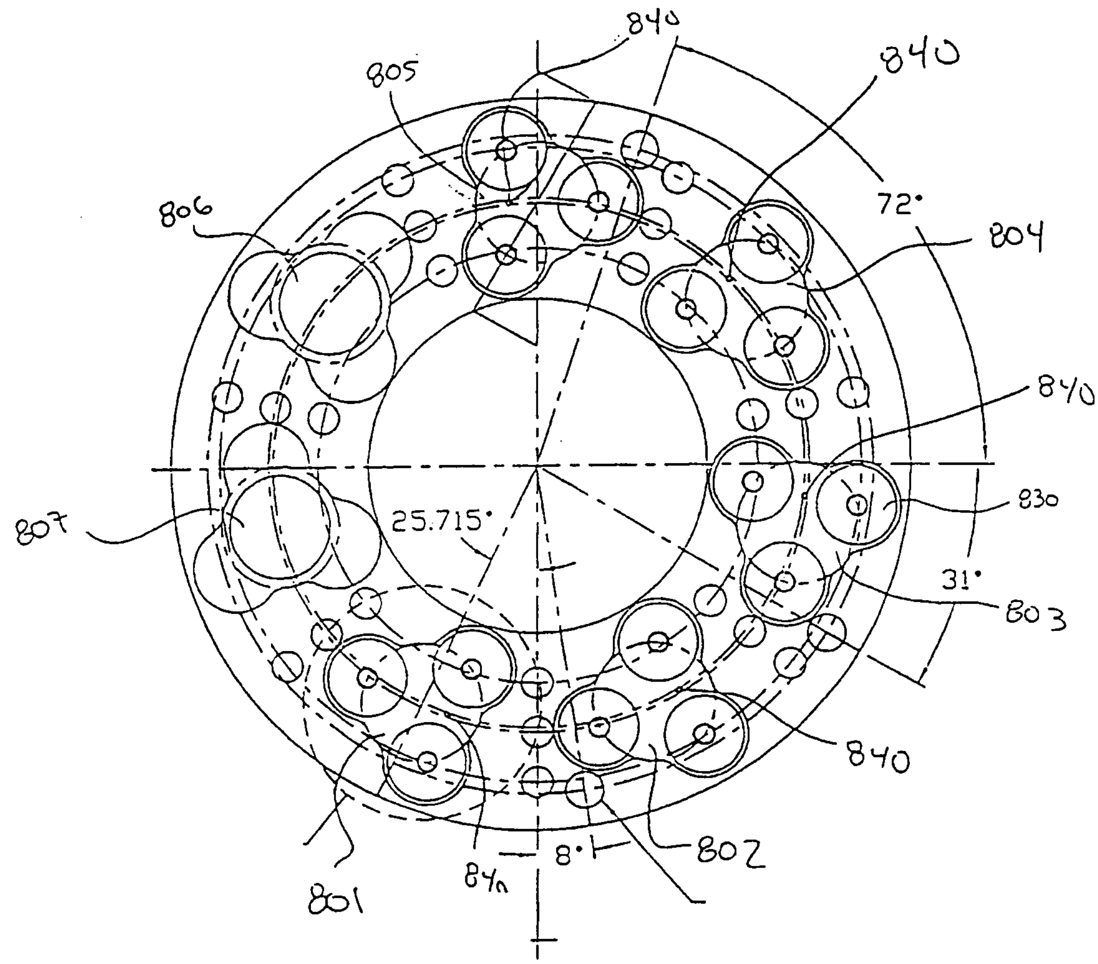


Fig. 8B

Base Plate

Top

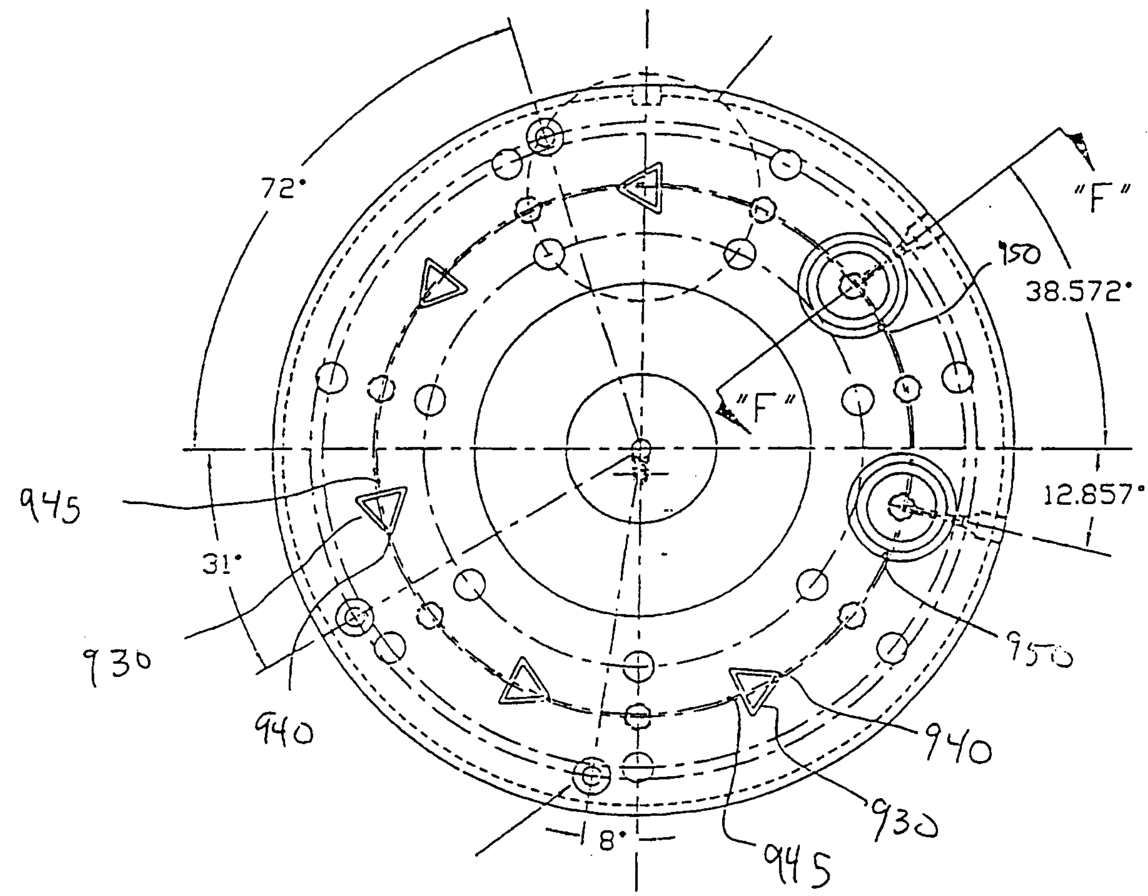


Fig. 9A

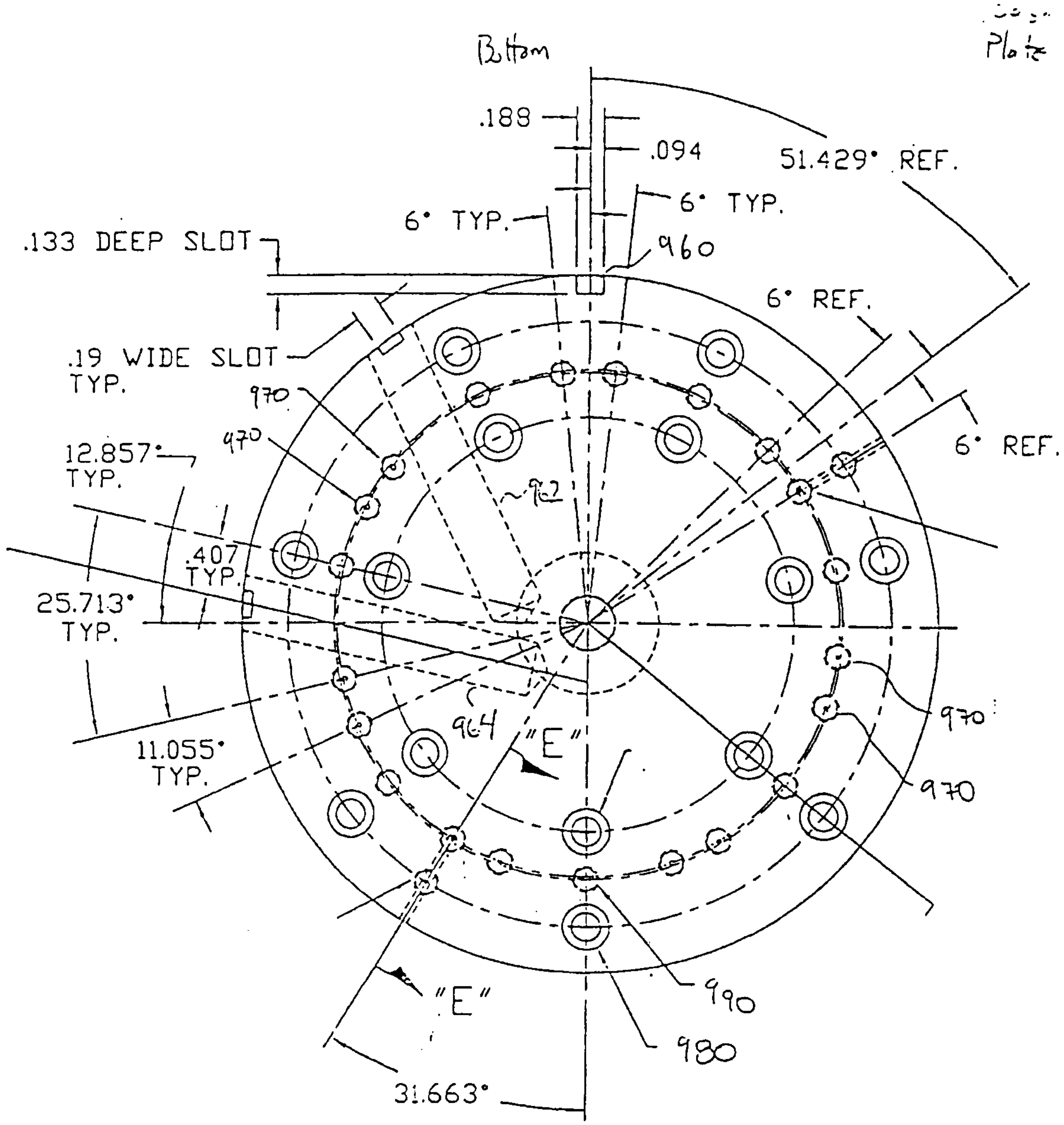

Bottom
Plate
.188
.094
51.429° REF.
6° TYP.
6° TYP.
.133 DEEP SLOT
960
6° REF.
.19 WIDE SLOT
TYP.
970
970
12.857°
TYP.
6° REF.
962
.407
TYP.
25.713°
TYP.
970
964
"E"
970
11.055°
TYP.
990
"E"
980
31.663°

Fig. 9B

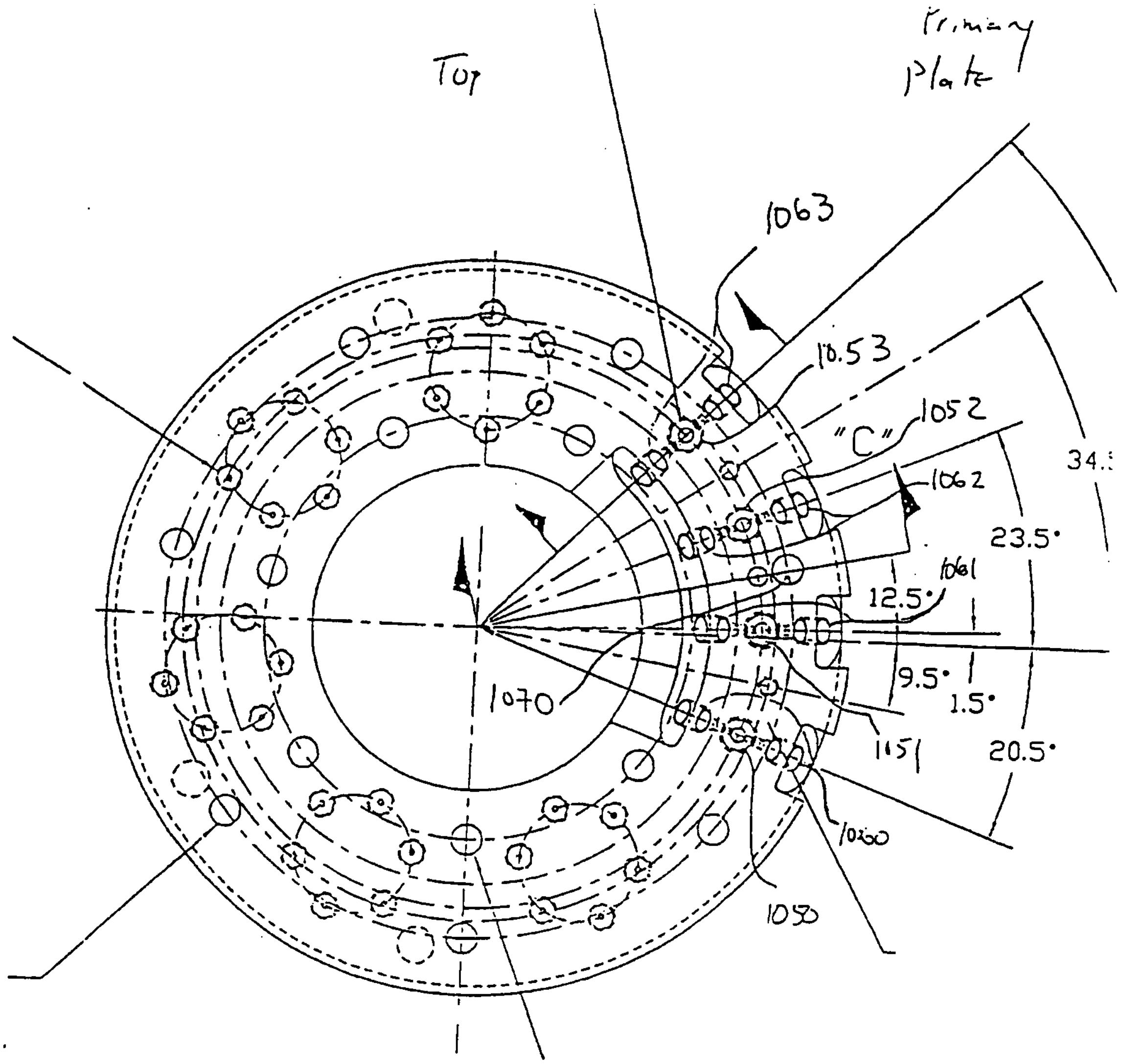

Top
Primary
Plate
1063
1053
"C"
1052
1062
34.5
23.5°
1061
12.5°
1070
9.5°
1.5°
1151
20.5°
1060
1050

Figure 10A

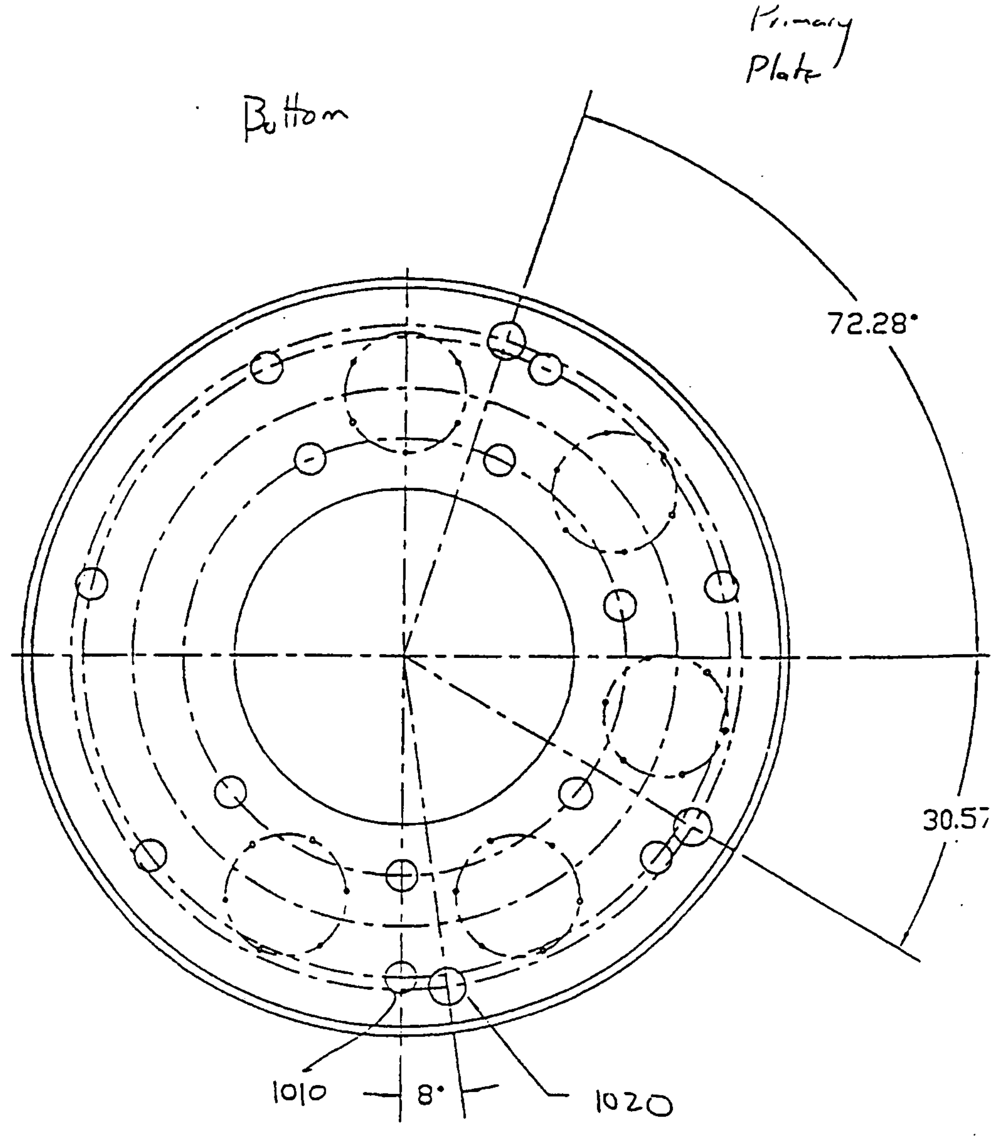


Figure 10B

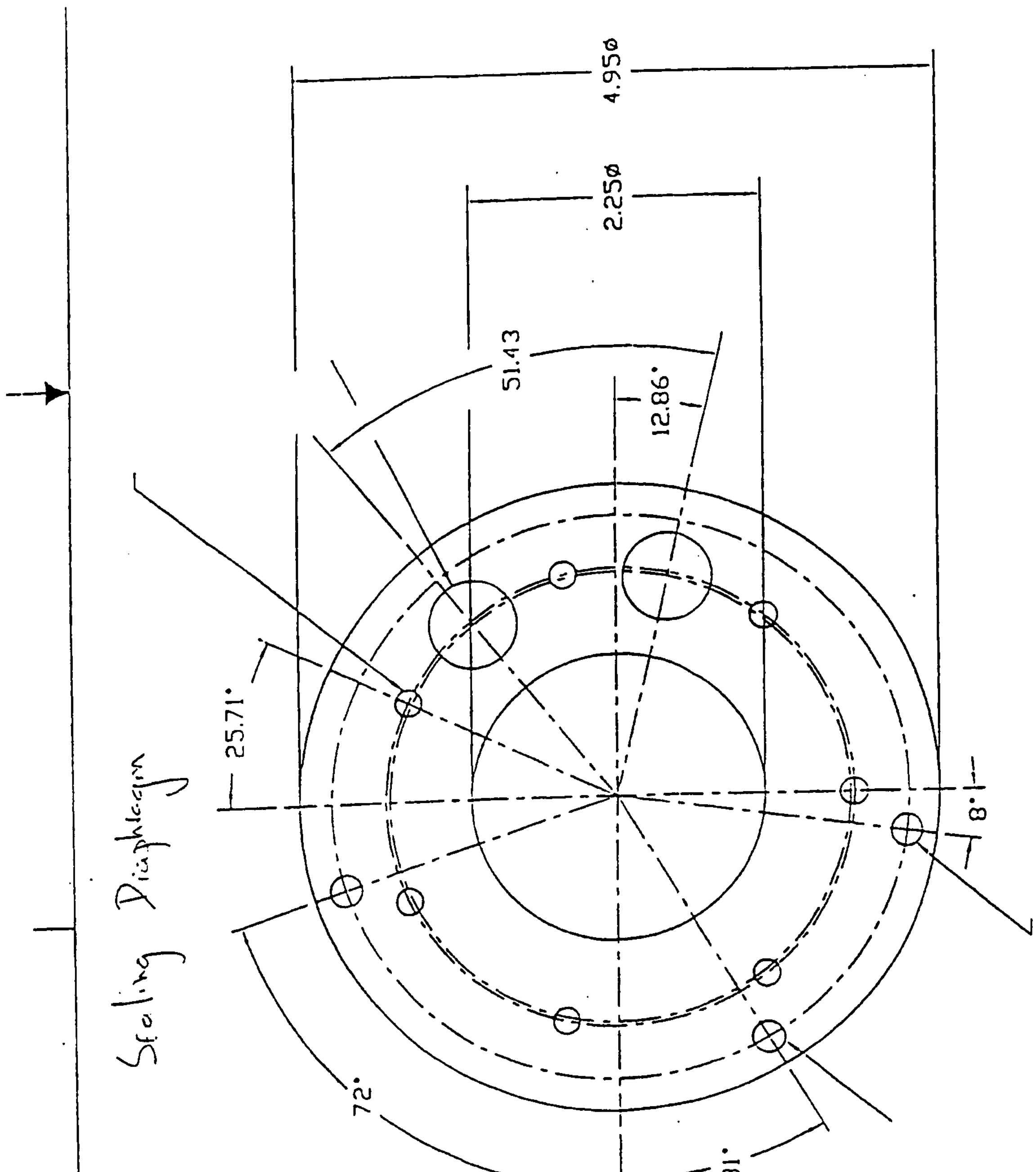


Fig. 11

Cushion Diaphragm

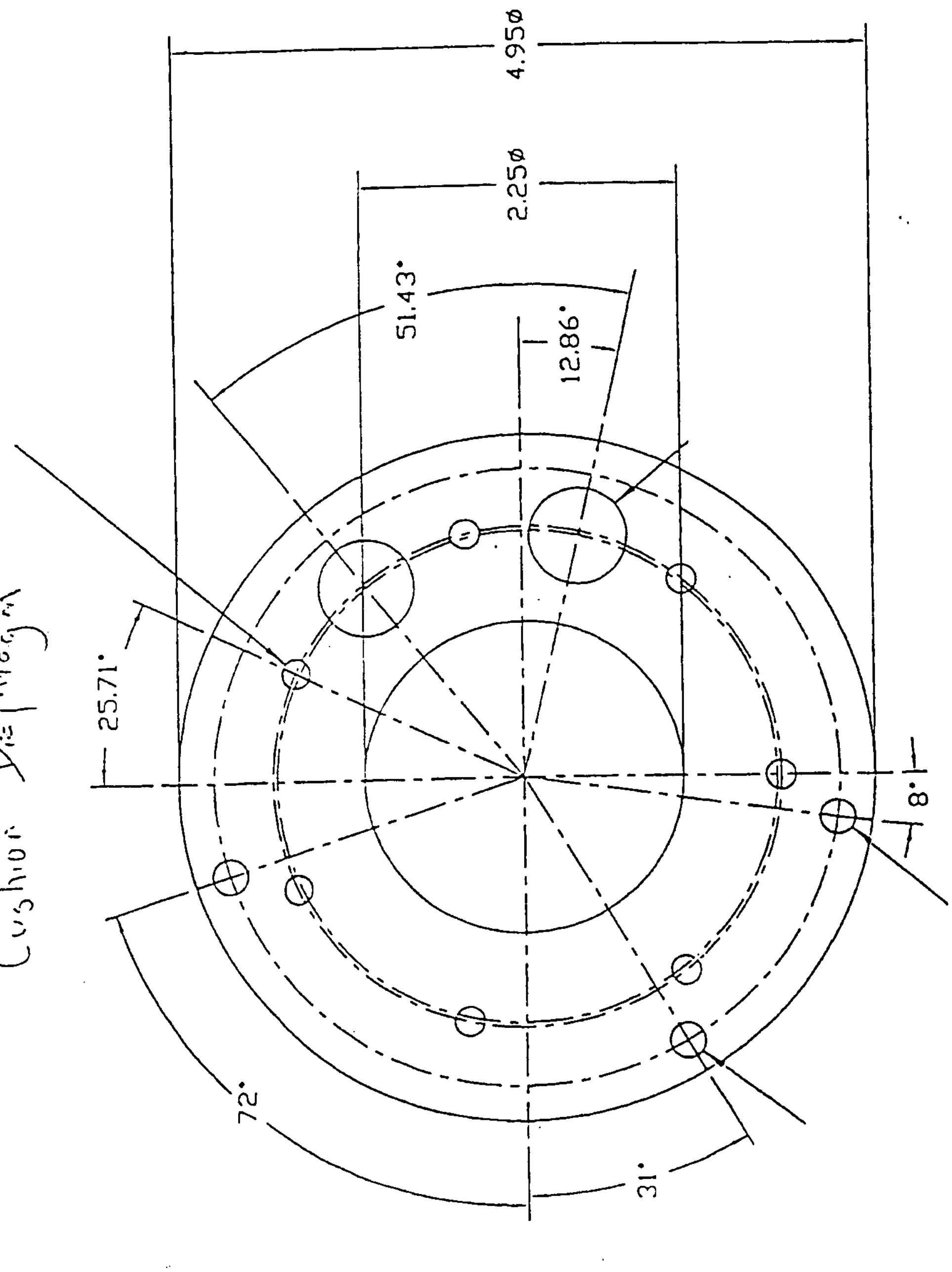


Figure 12

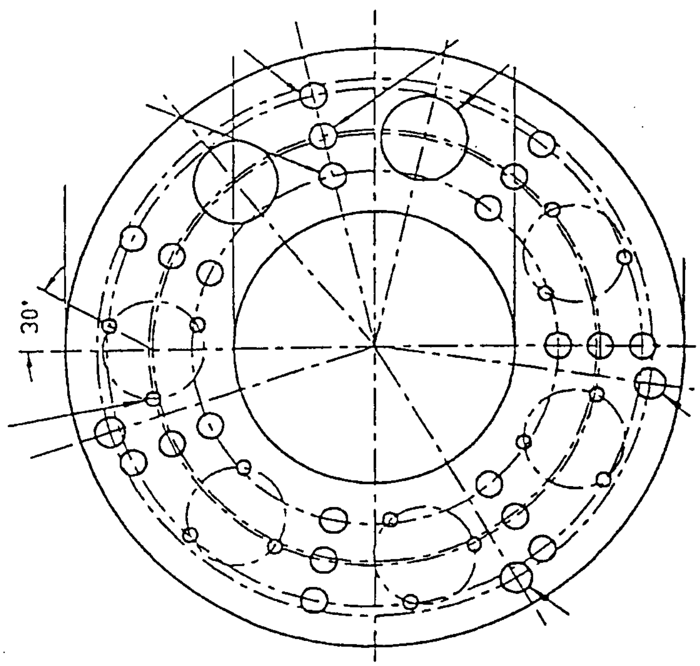


Figure 13a

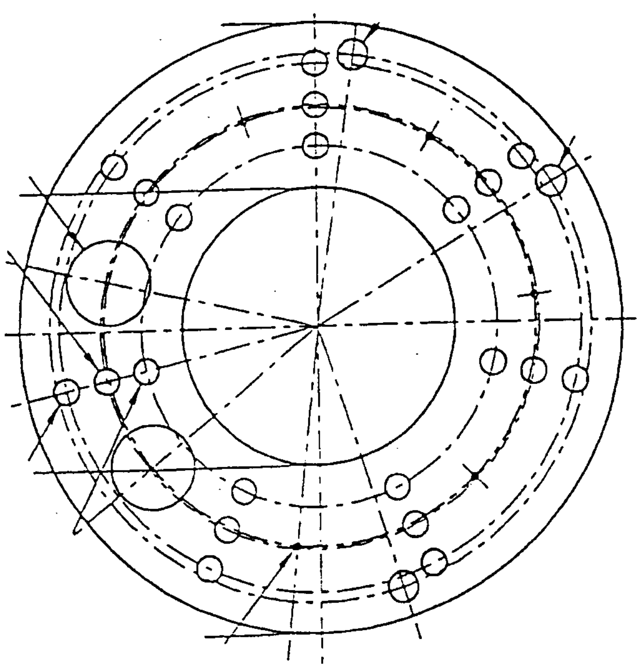


Figure 13b

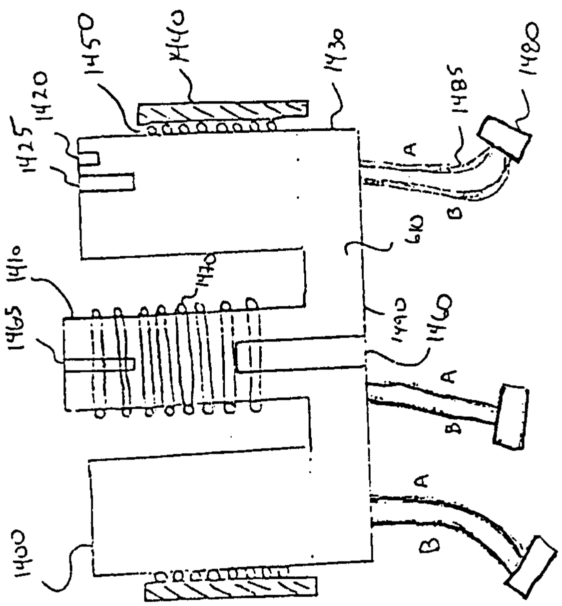

1400
1410
1420
1425
1430
1440
1450
1460
1465
1470
1480
1485
1490
610
A
B
A
B
A
B

Fig. 14

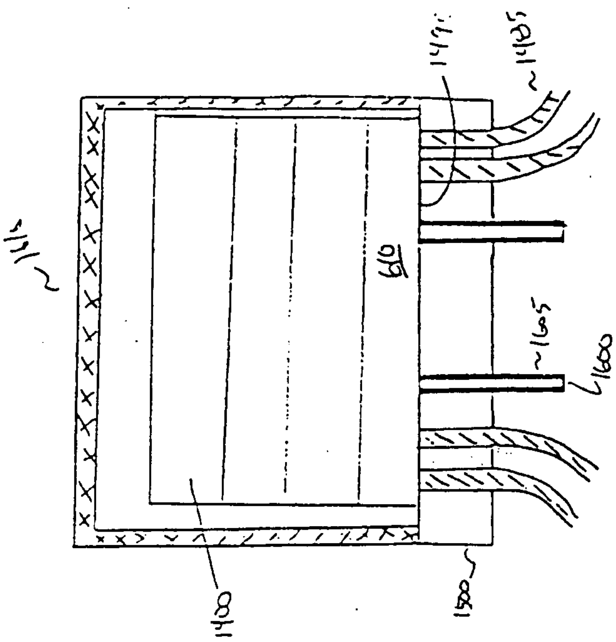


Fig. 16

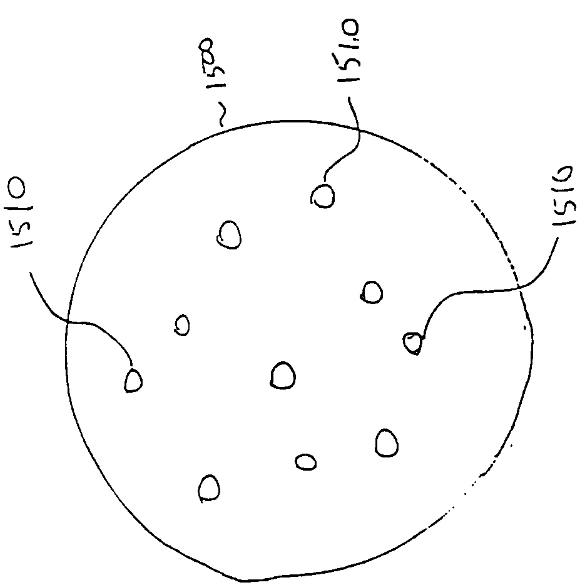


Fig. 15

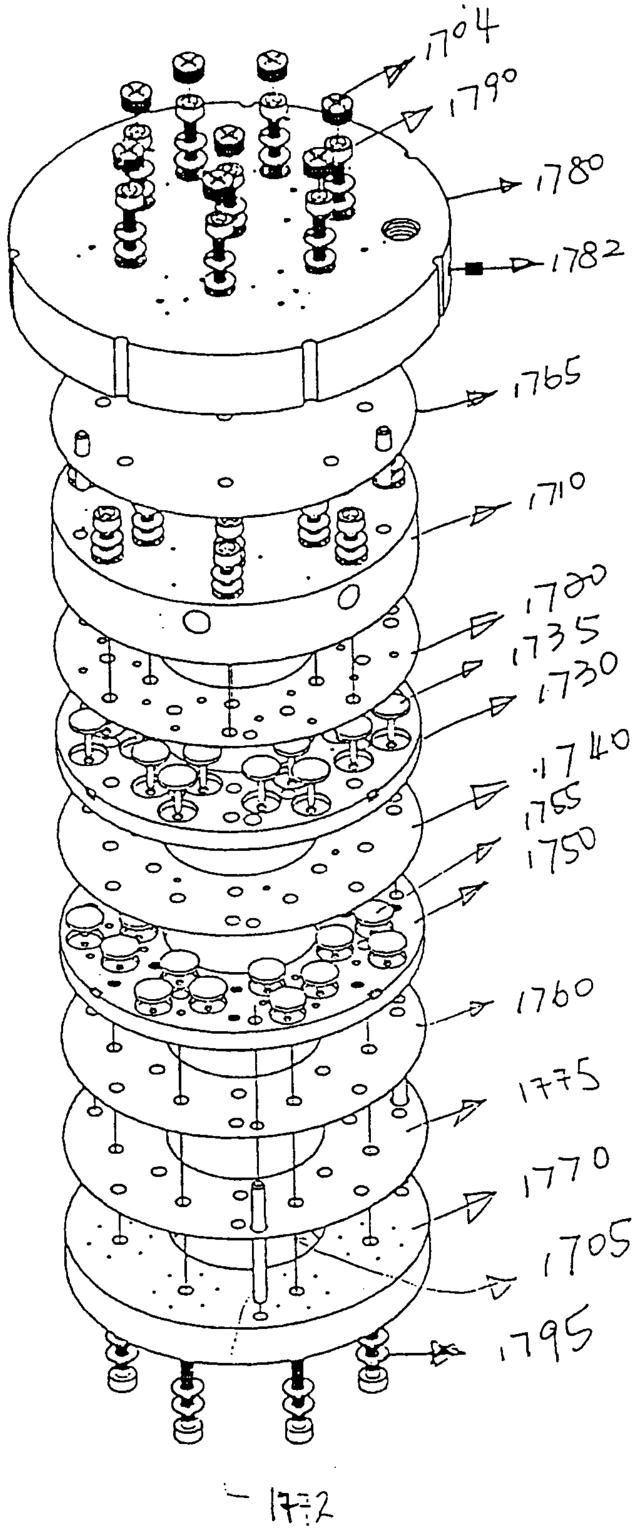

1704
1790
1780
1782
1765
1710
1720
1735
1730
1740
1755
1750
1760
1775
1770
1705
1795
1772

Figure 17

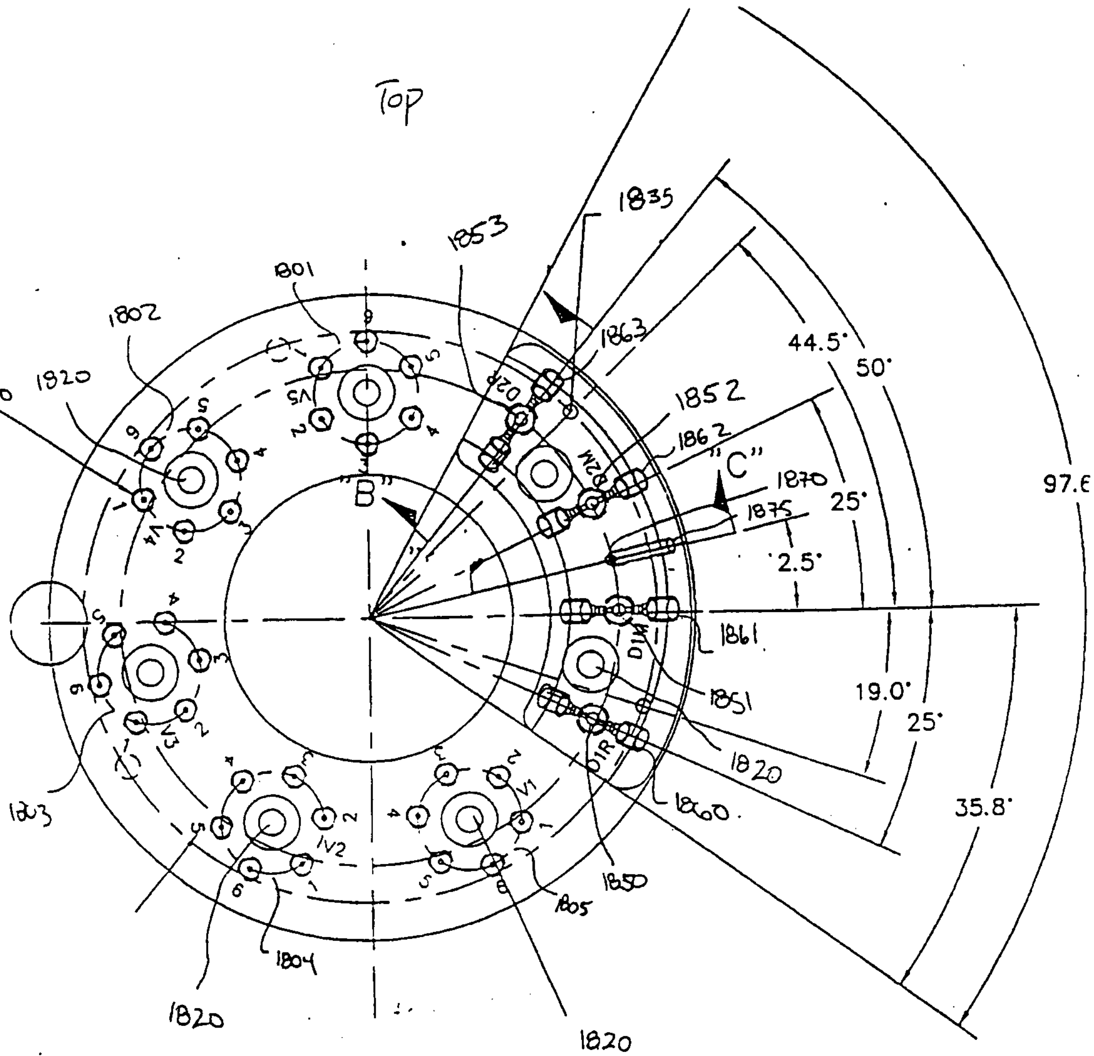

Top
1835
1853
1801
1802
1820
1810
1863
44.5°
50°
1852
1862
"C"
1870
1875
25°
97.6
"B"
2.5°
1861
1851
19.0°
25°
1820
1860
35.8°
1803
1850
1805
1804
1820
1820
V1
V2
V3
V4
V5
D2P
D1R

Fig. 18 A

Bottom

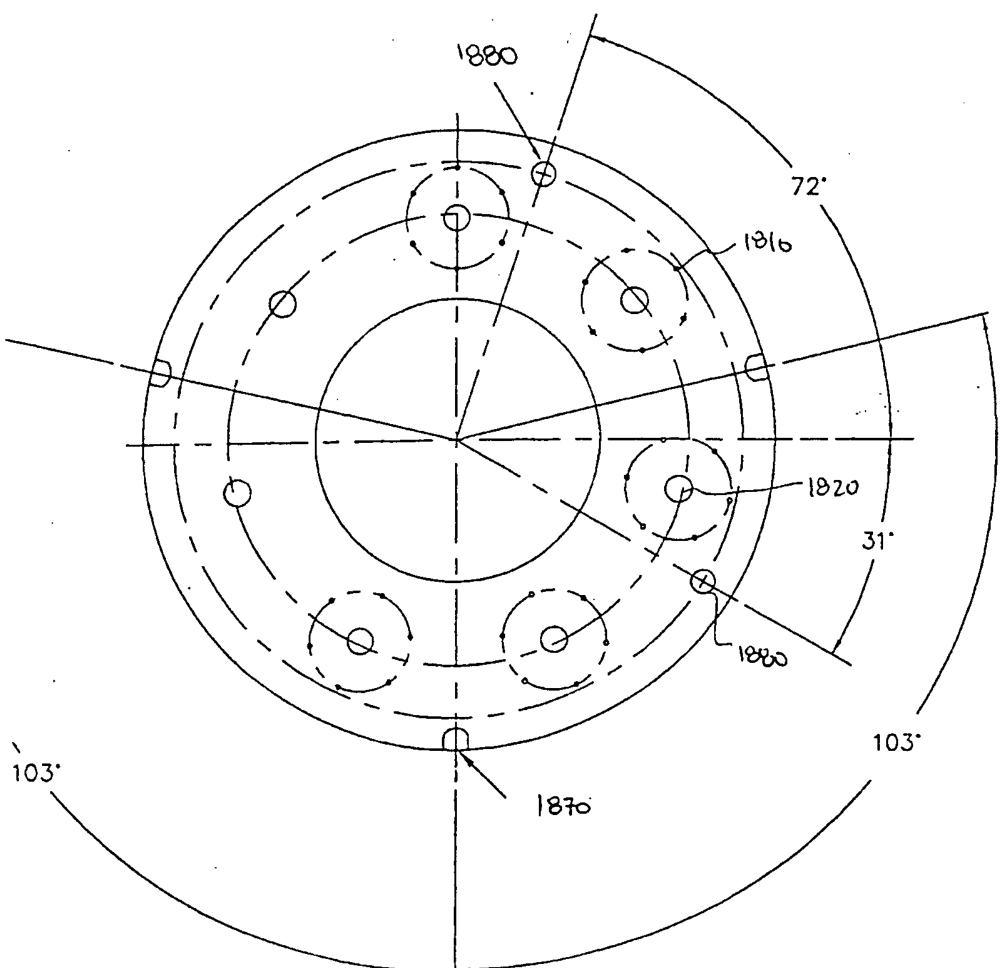


Fig. 18B

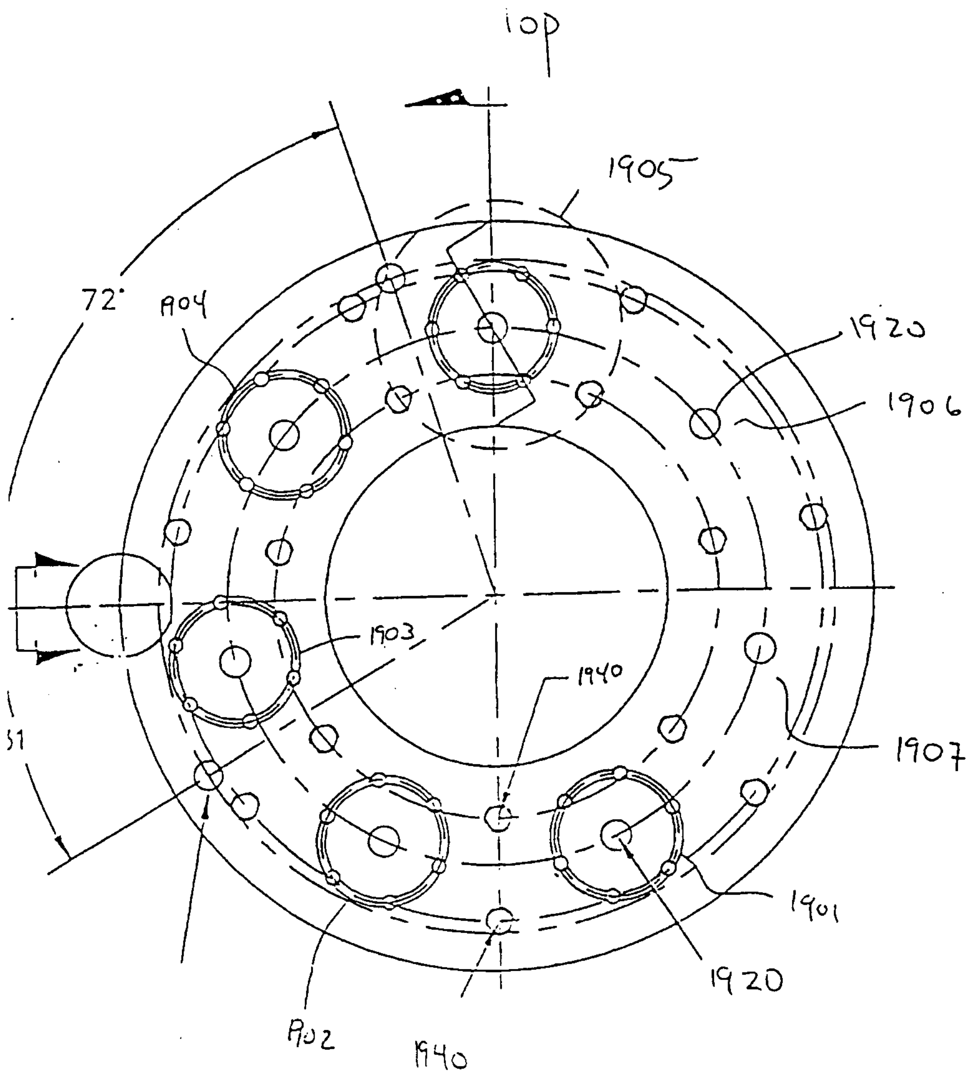


Fig. 19A

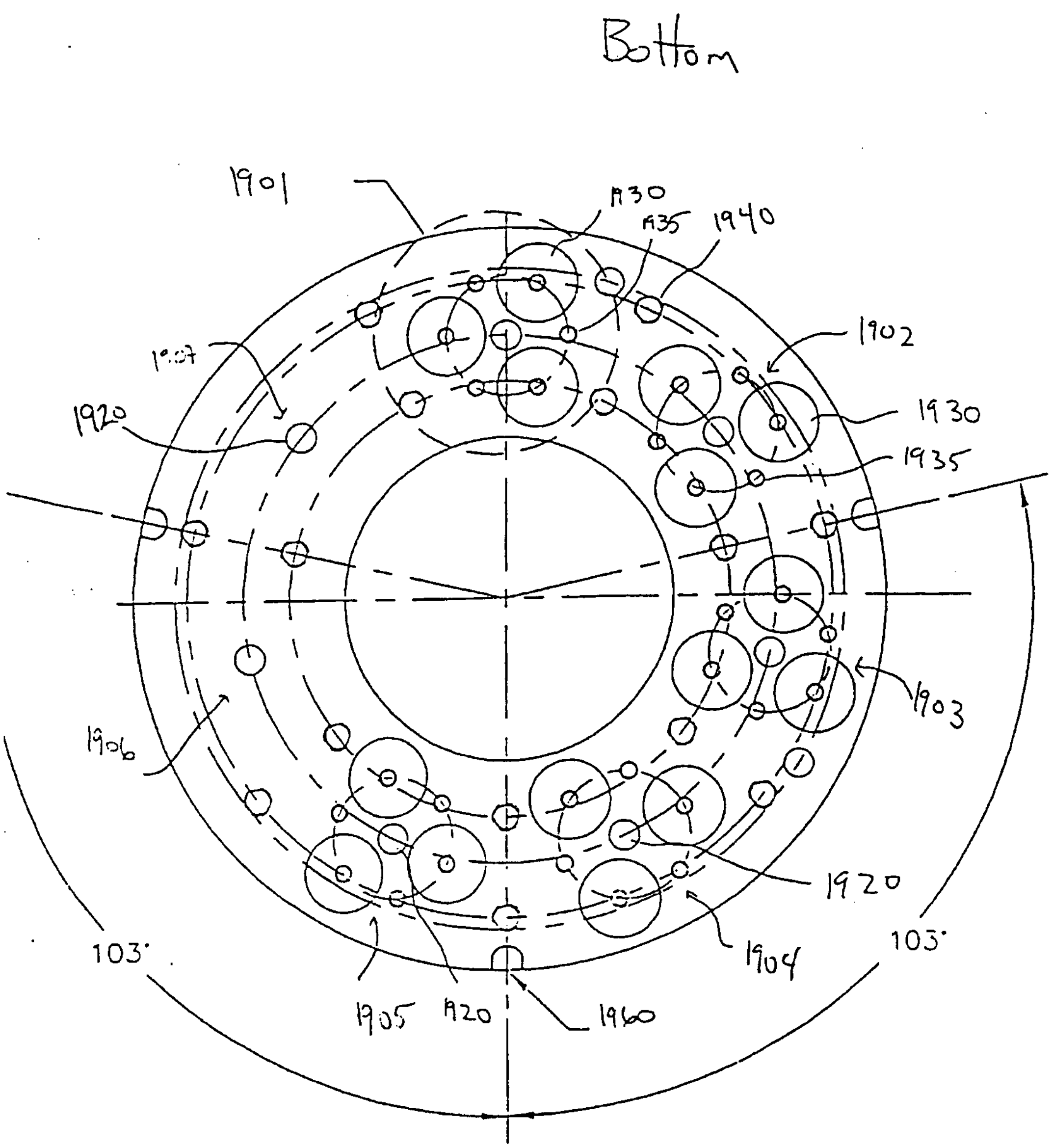

Bottom
1901
1930
1935
1940
1902
1907
1920
1930
1935
1906
1903
1920
103°
105°
1904
1905
1920
1960

Fig. 19B

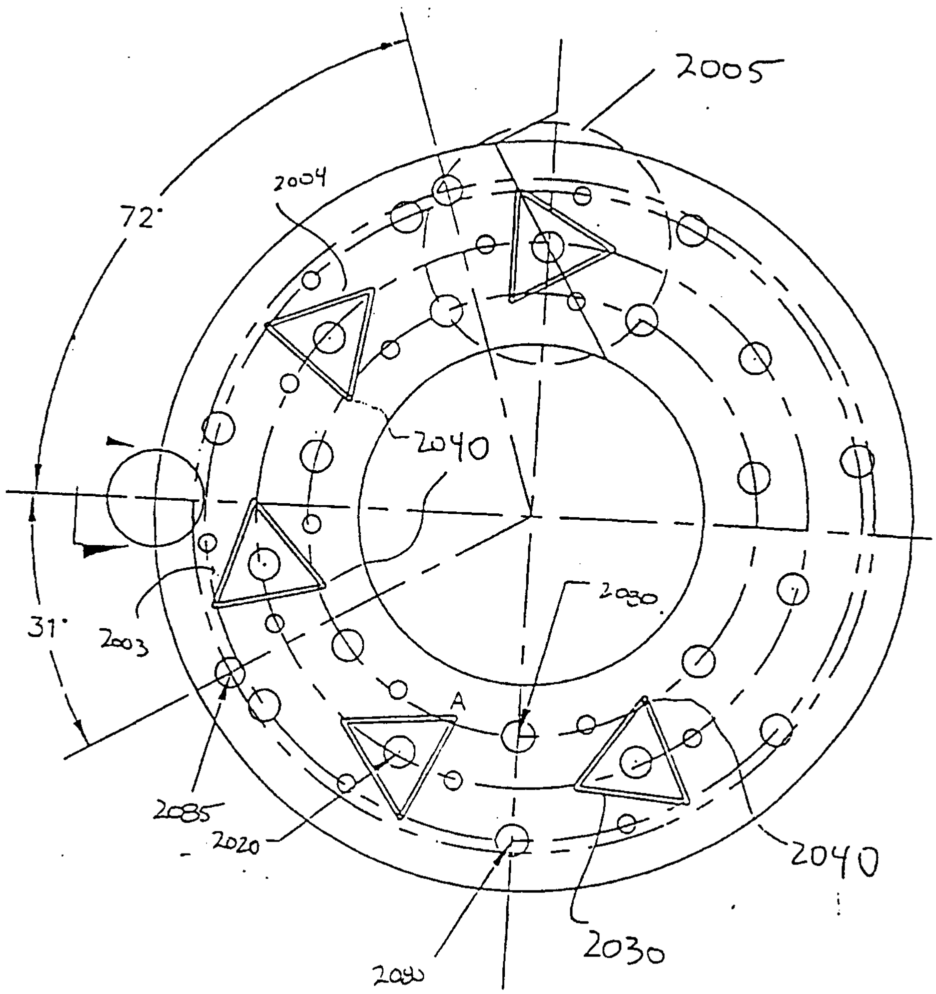


Fig. 20A

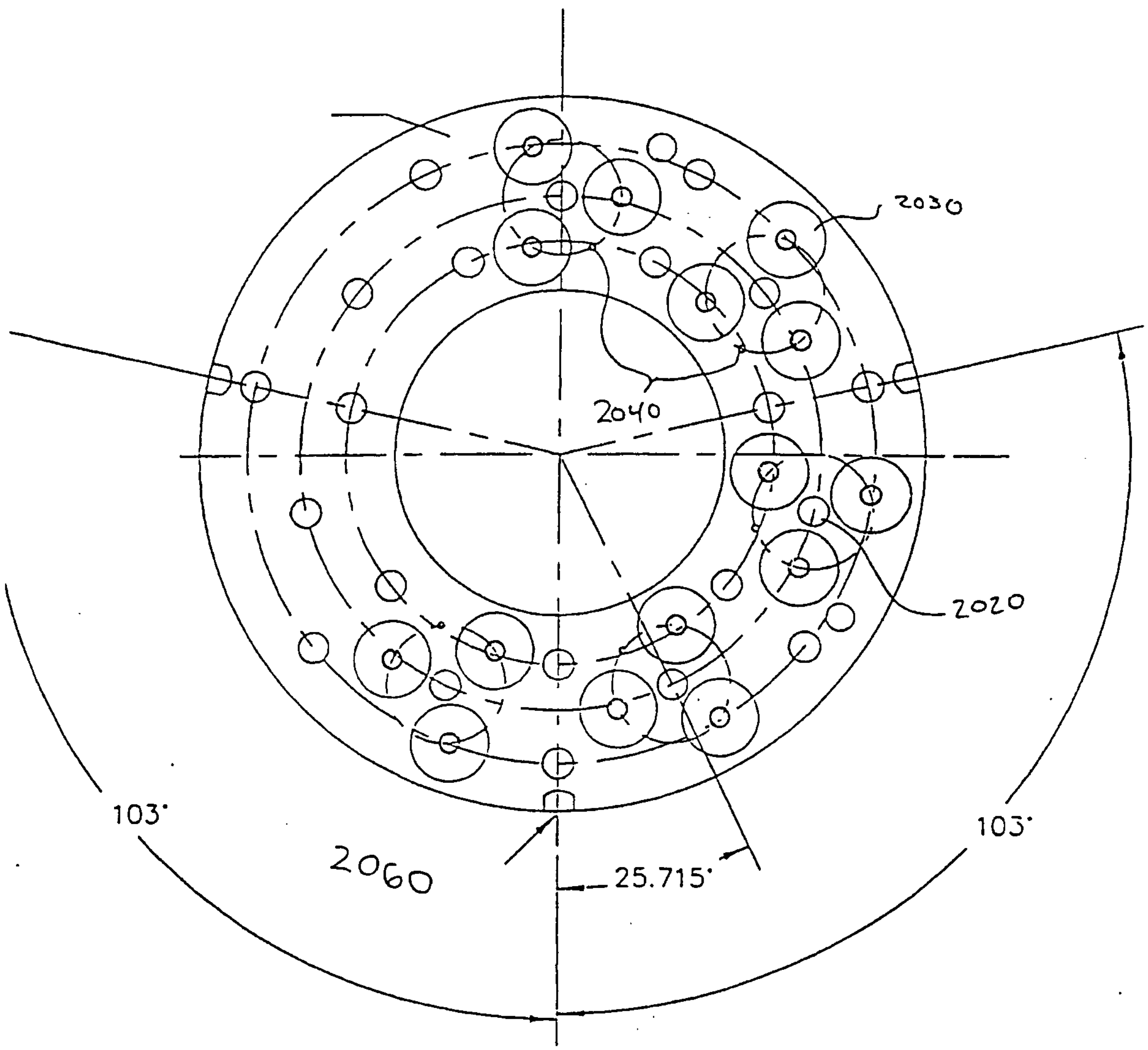


Fig. 20B

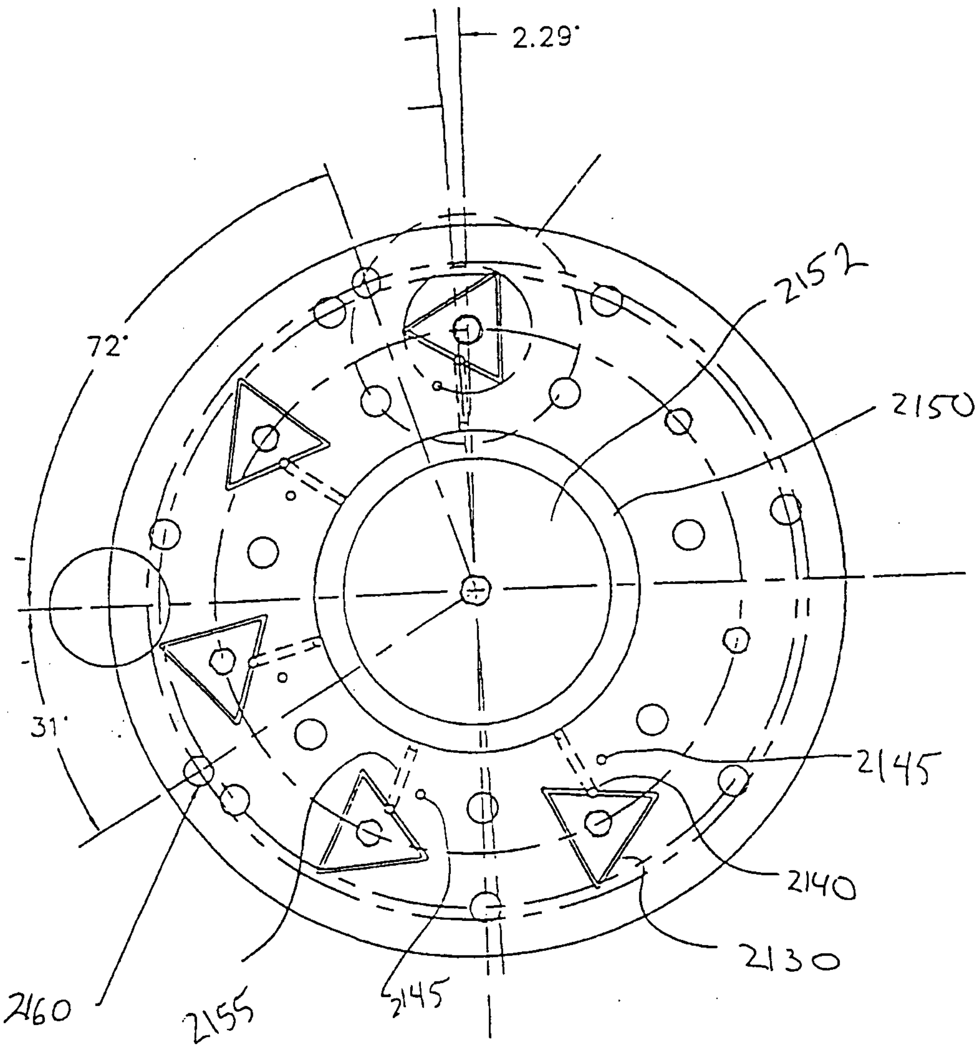


Fig. 21A

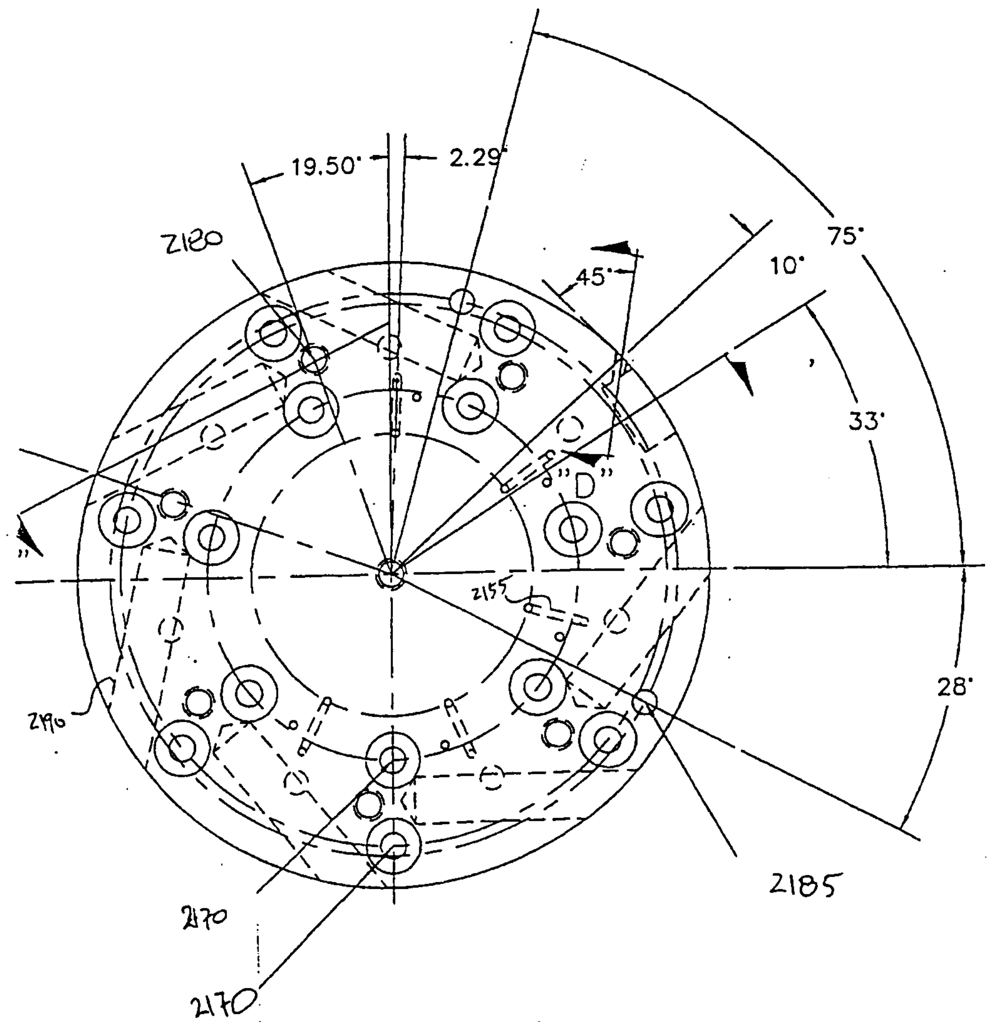


Fig. 21B

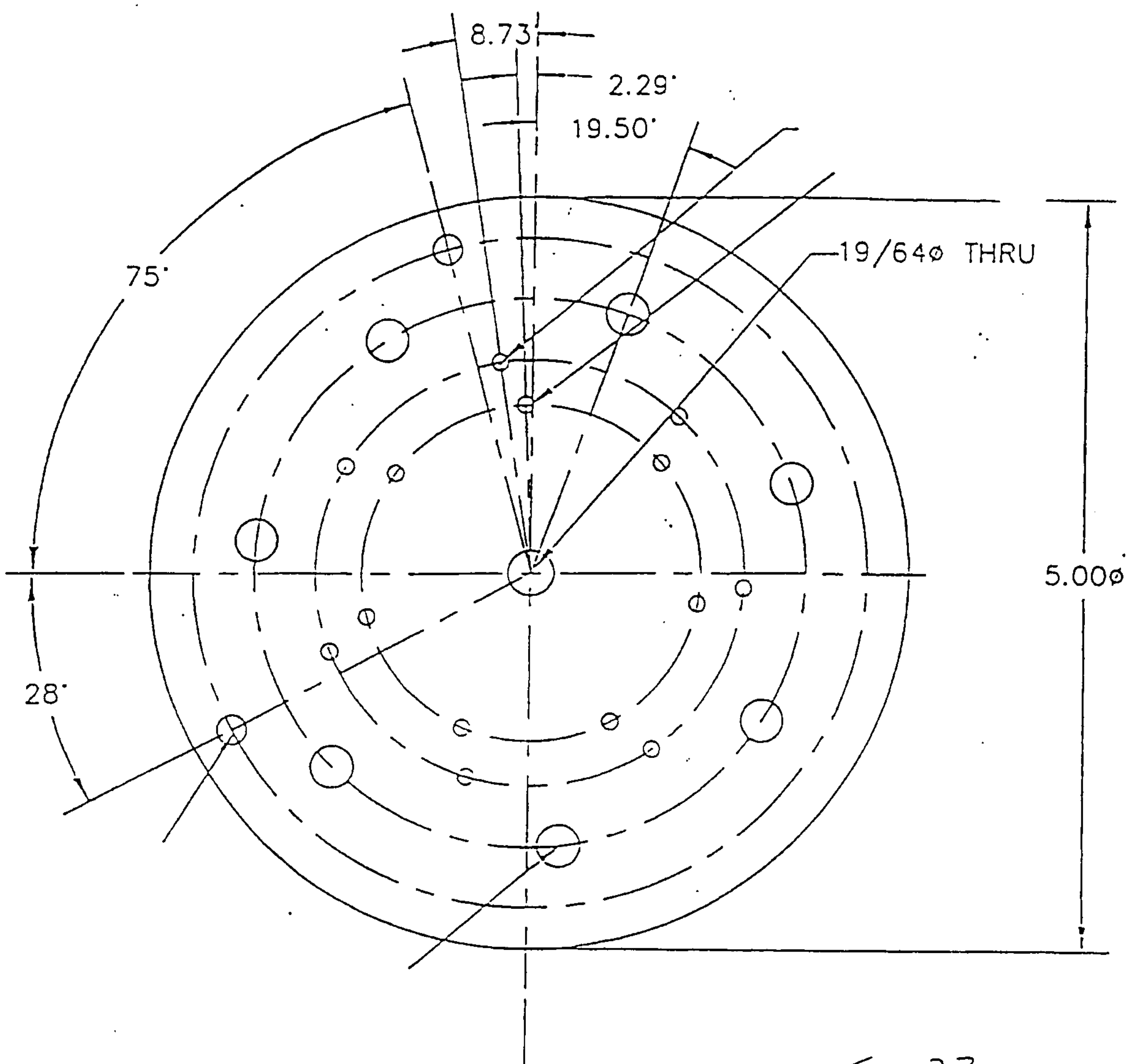


Fig. 22

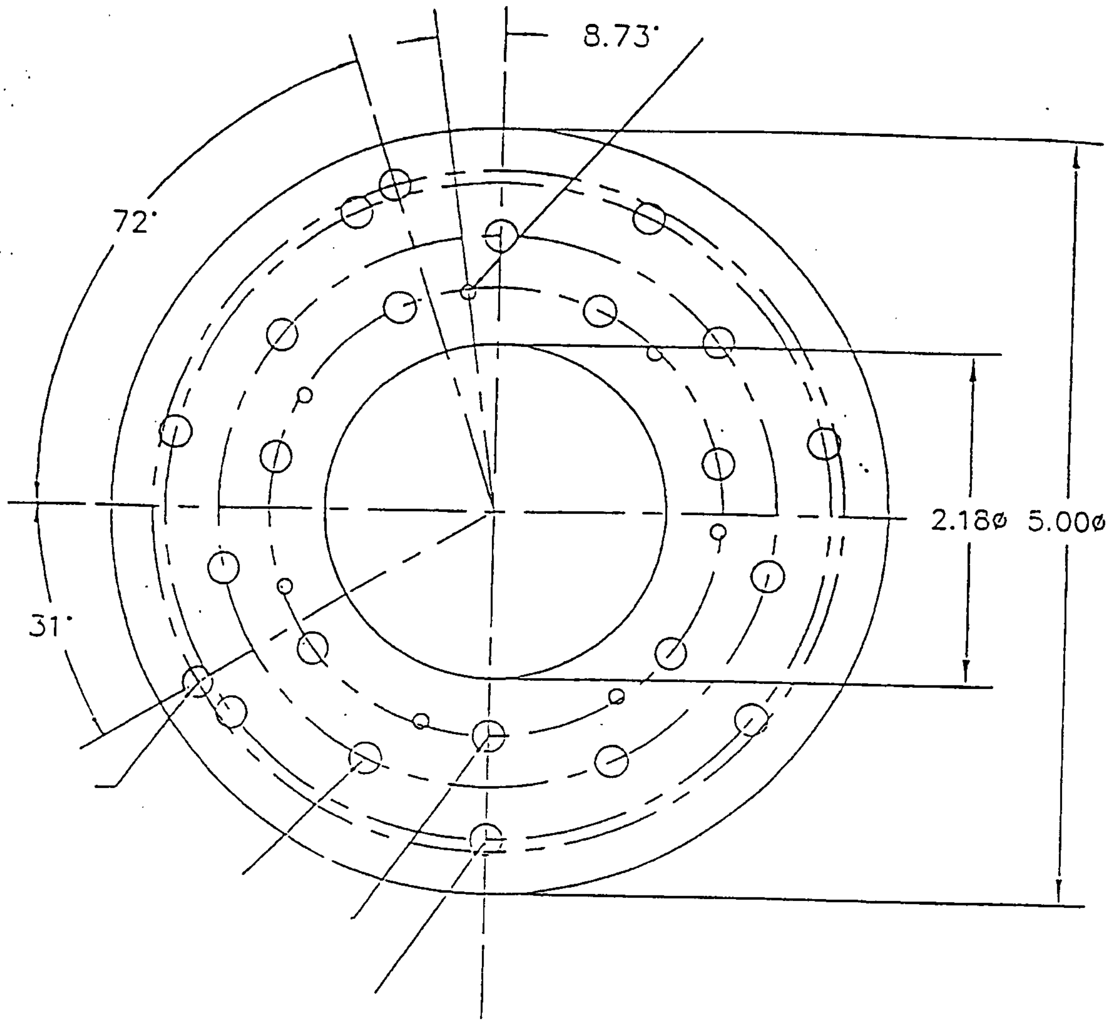


Fig. 23

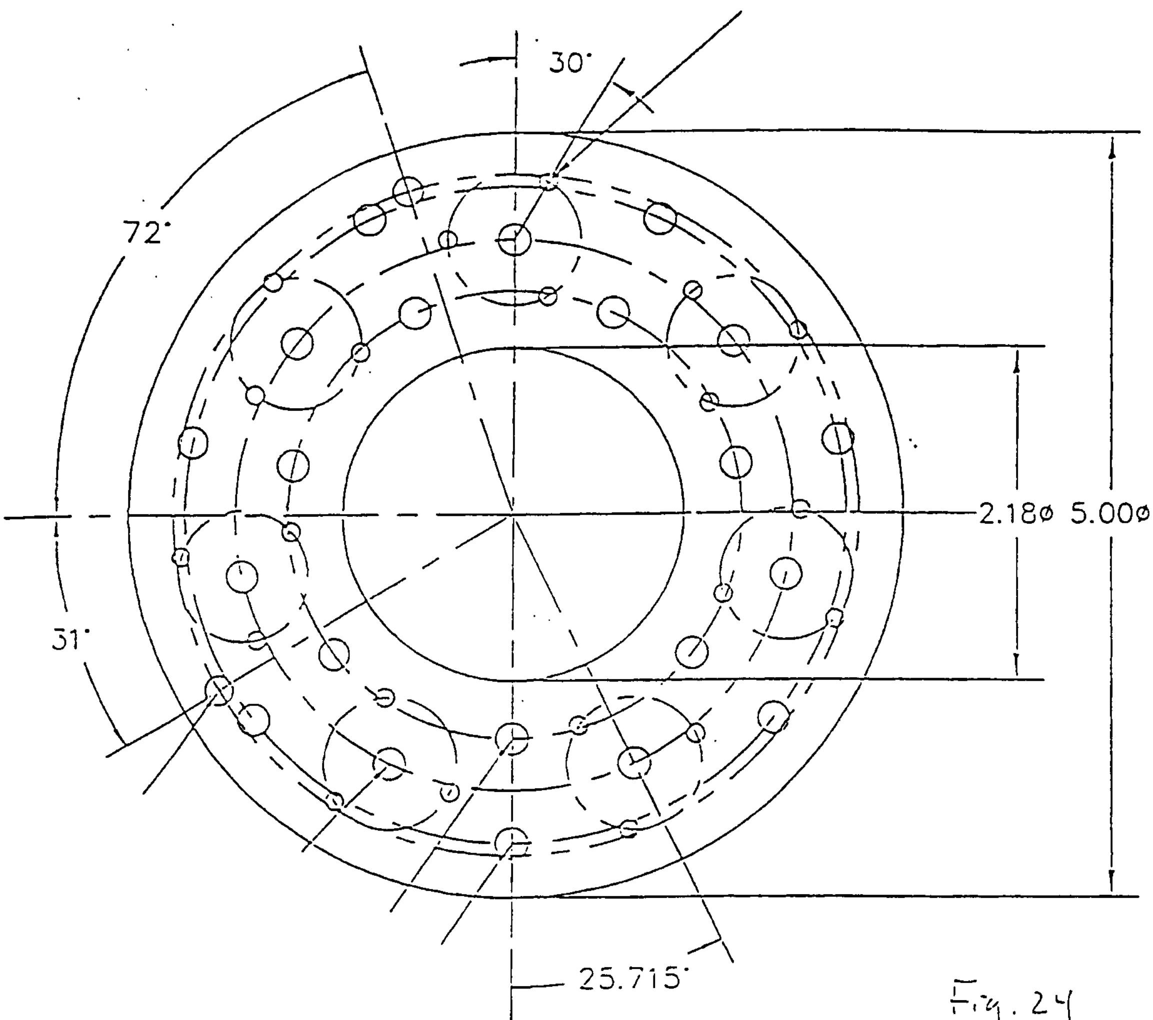


Fig. 24

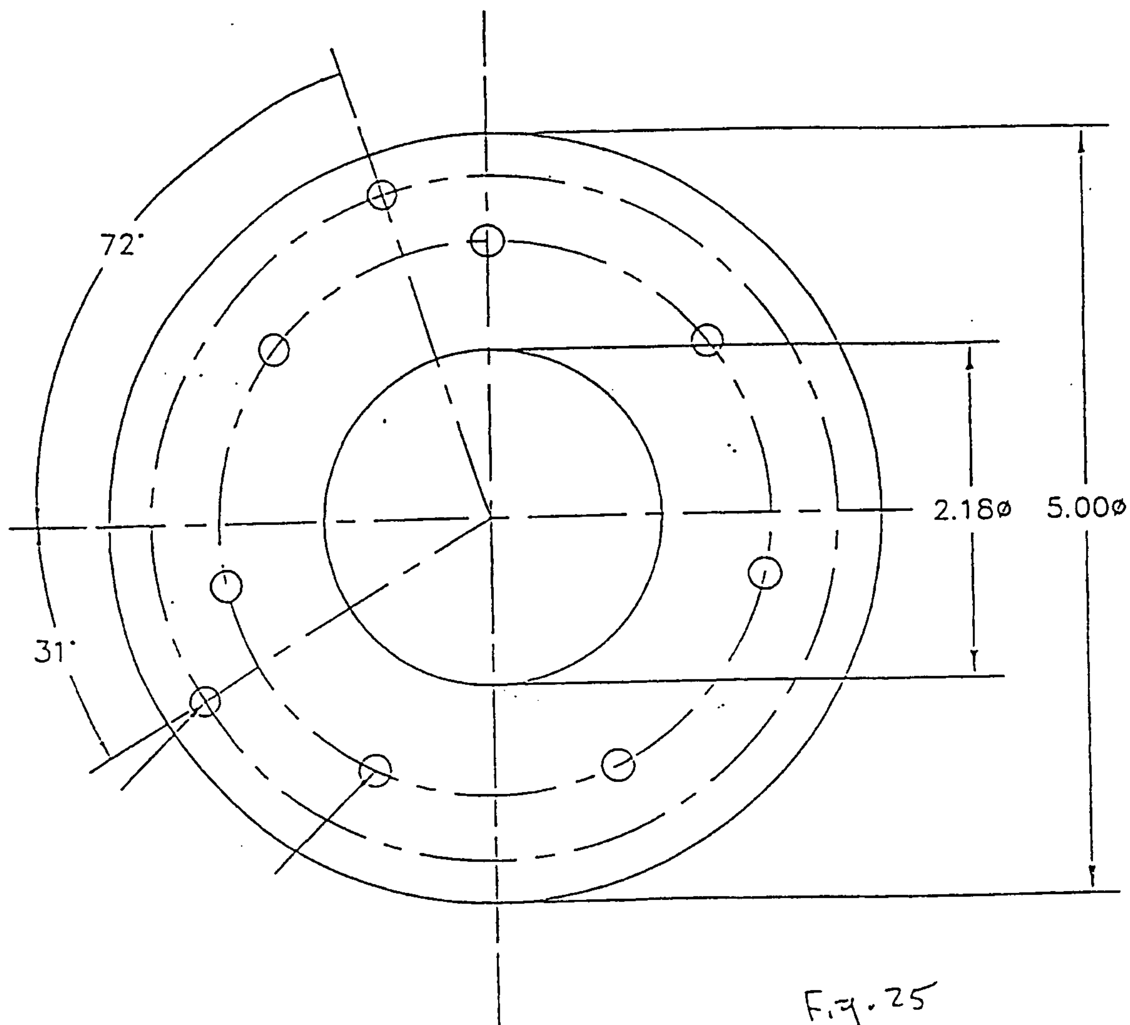


Fig. 25

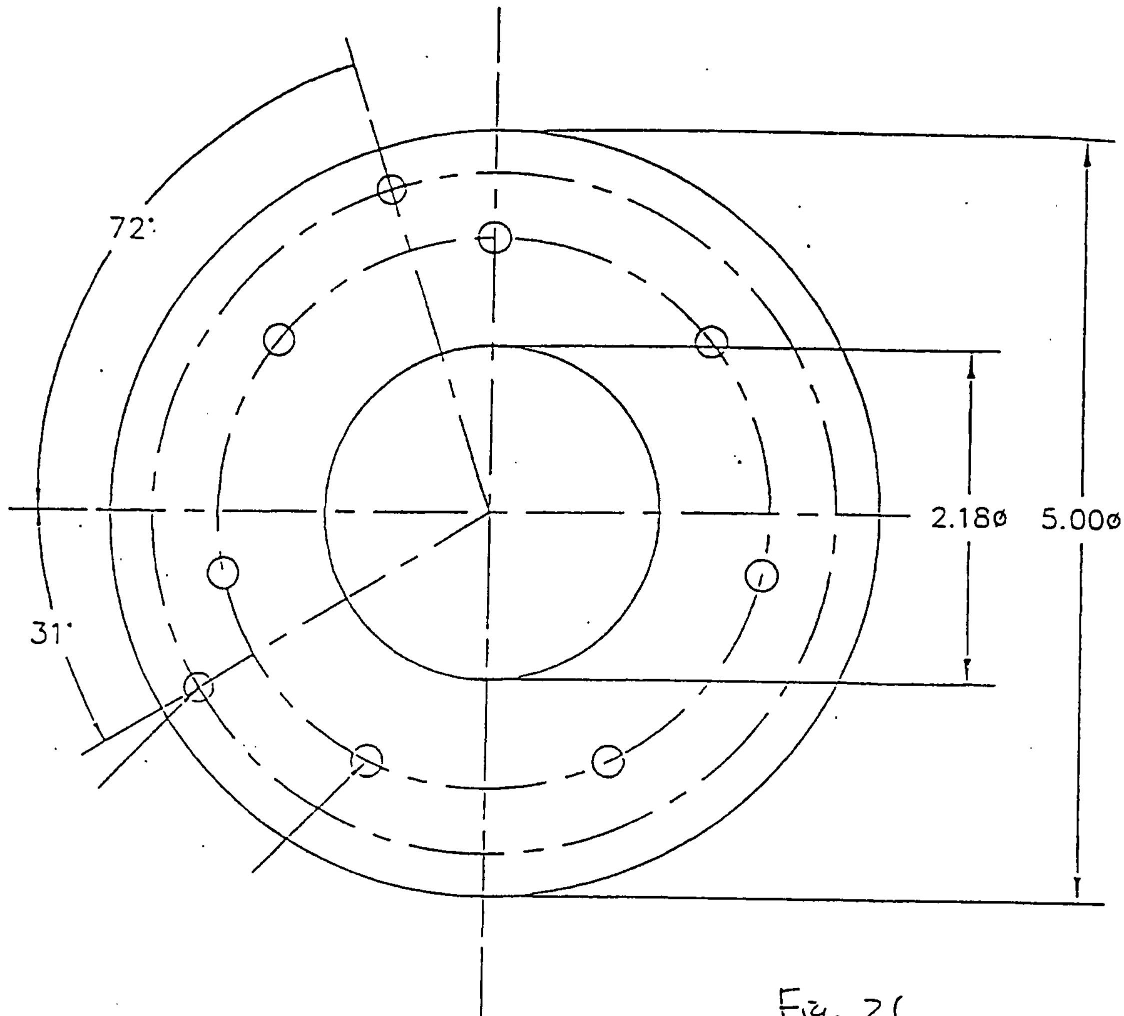


Fig. 26

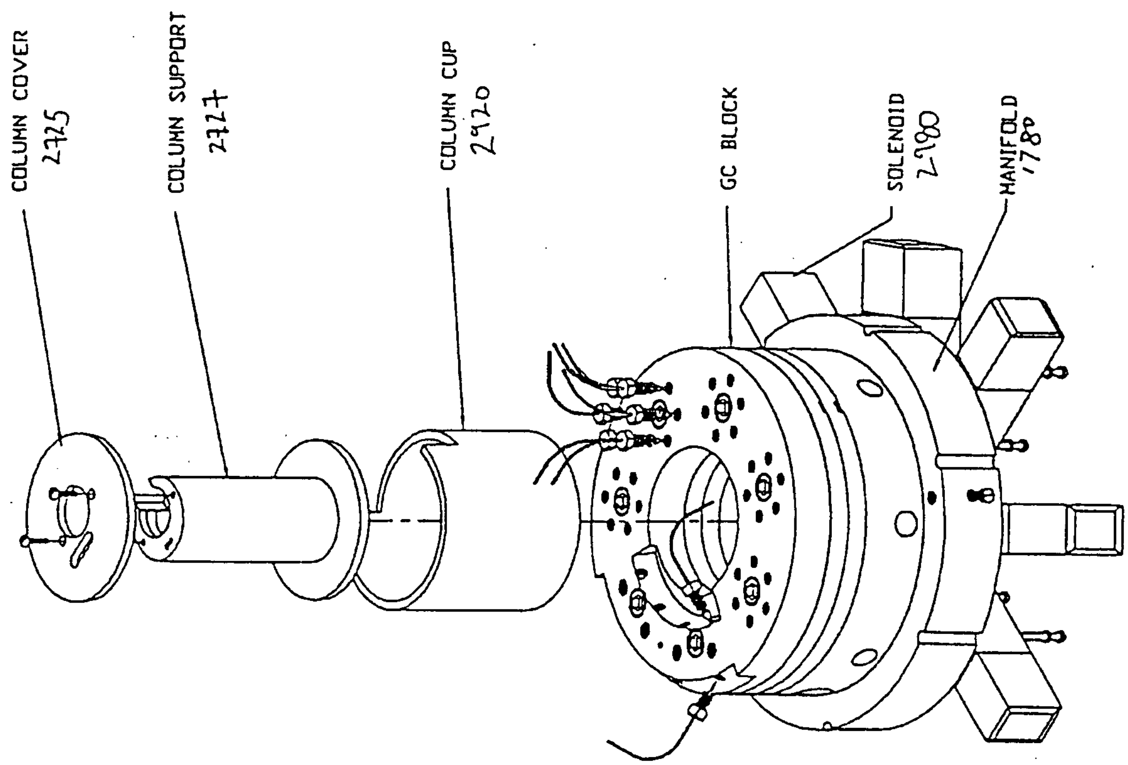
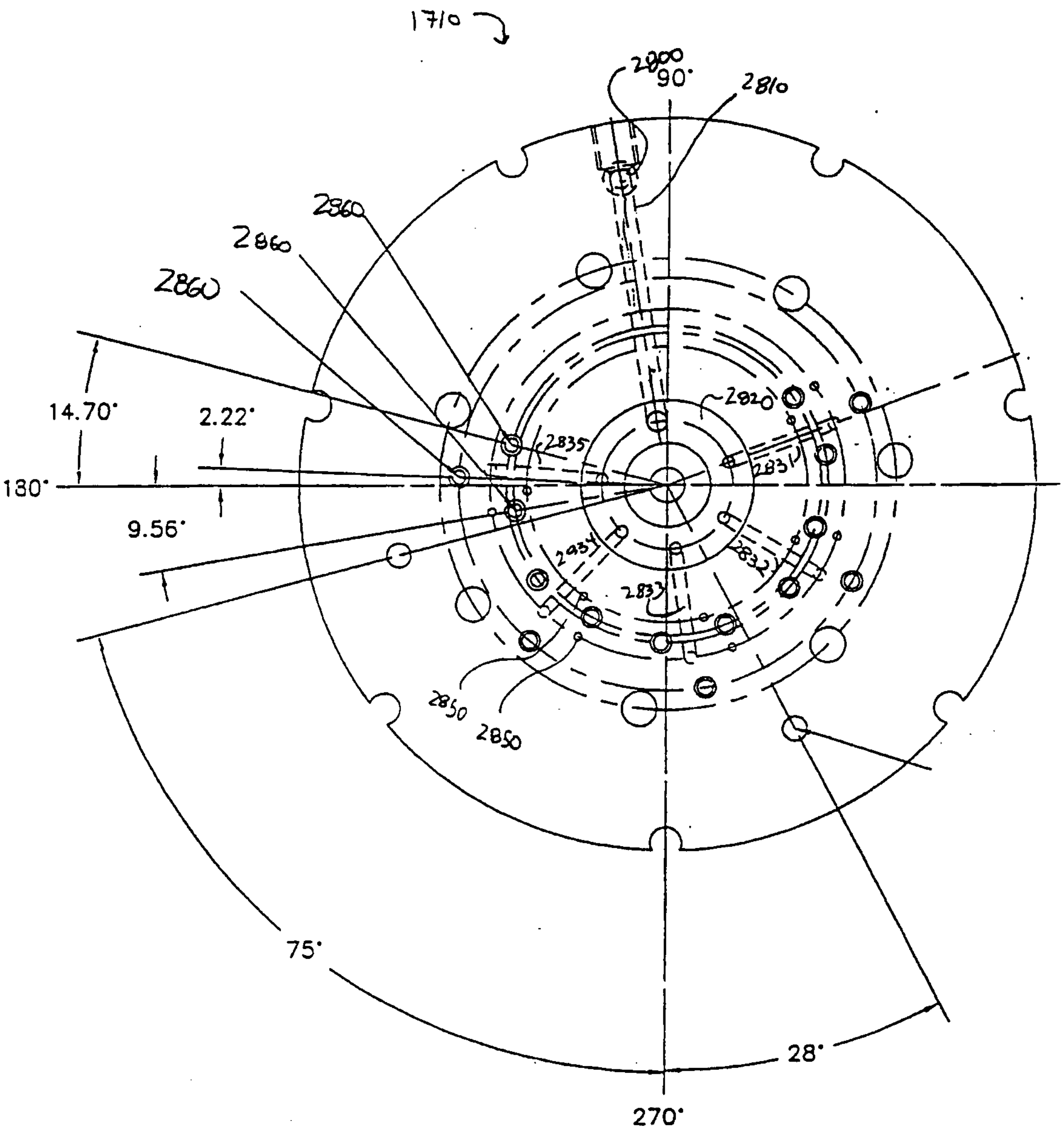

COLUMN COVER
2725
COLUMN SUPPORT
2727
COLUMN CUP
2720
GC BLOCK
SOLENOID
2780
MANIFOLD
1780

Figure 27


1710
2800
90°
2810
2860
2860
2860
2820
2835
2831
14.70°
2.22°
180°
9.56°
2934
2833
2832
2850
2850
75°
28°
270°

TOP

Fig. 28A

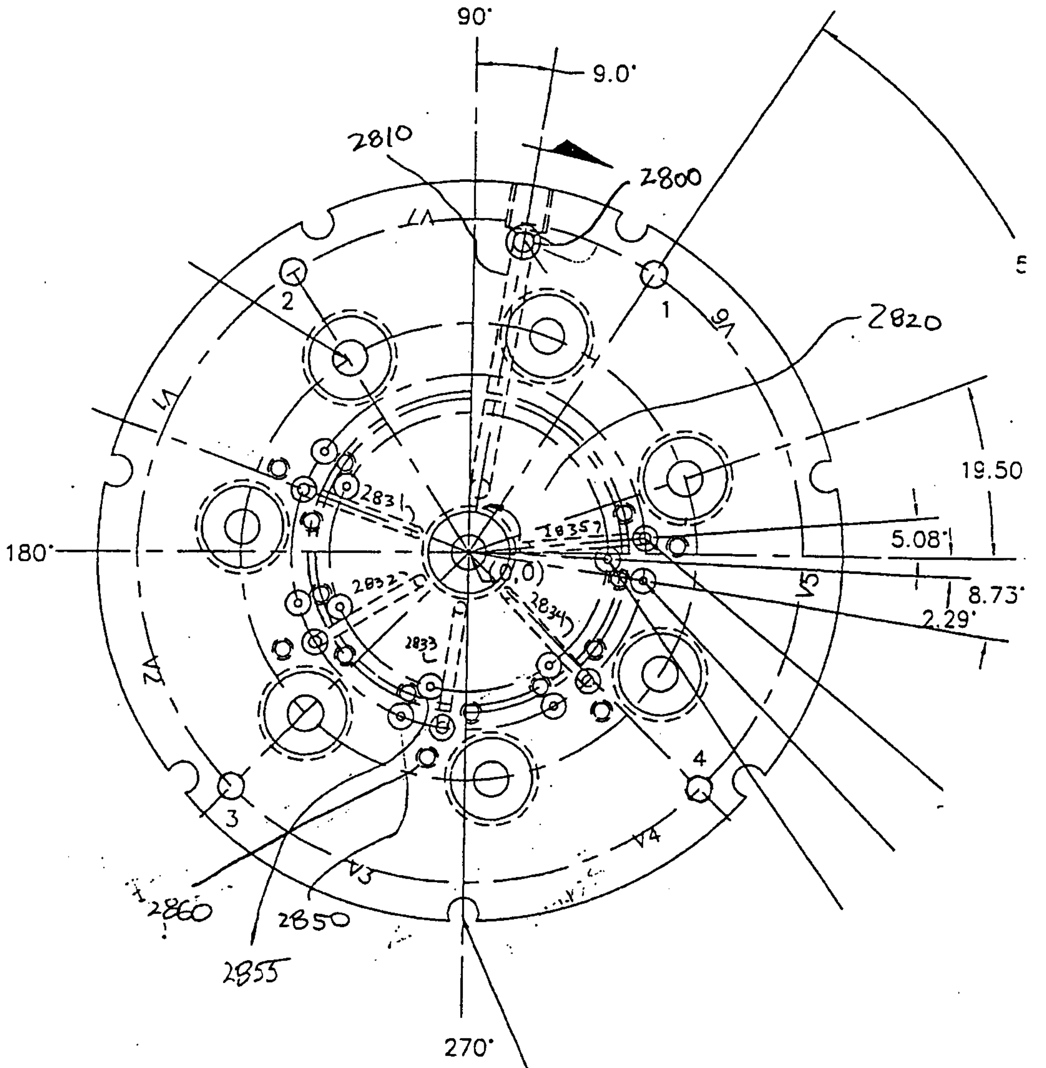


Fig-28B

BOTTOM

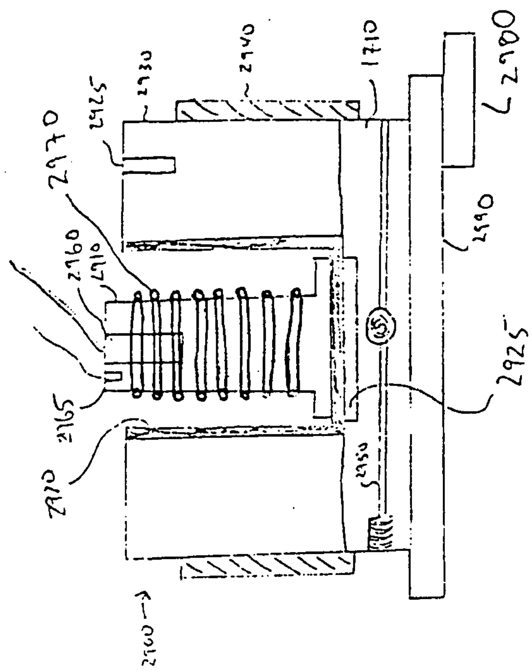

2970
2925
2930
2940
1710
2980
2990
2960
2910
2965
2920
2925
2950
2900

Fig. 29

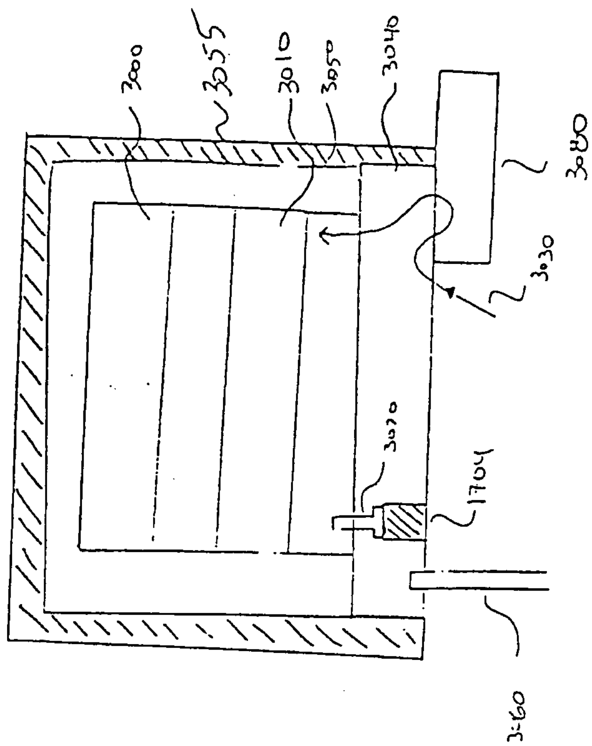


Fig. 30

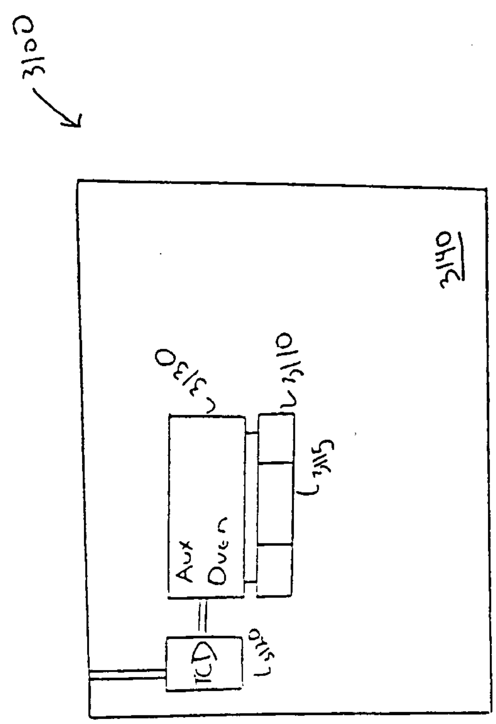


Fig. 31